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# PLANTERS' RECORD

VOL. XLVIII

A quarterly paper devoted to the sugar interests of Hawaii, and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

JANUARY TO DECEMBER

# THE HAWAIIAN PLANTERS' RECORD

## VOL. XLVIII

H. L. LYON, *Editor*

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W. L. McCLEERY
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*Associate Editors*

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ORGAN OF THE EXPERIMENT STATION OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

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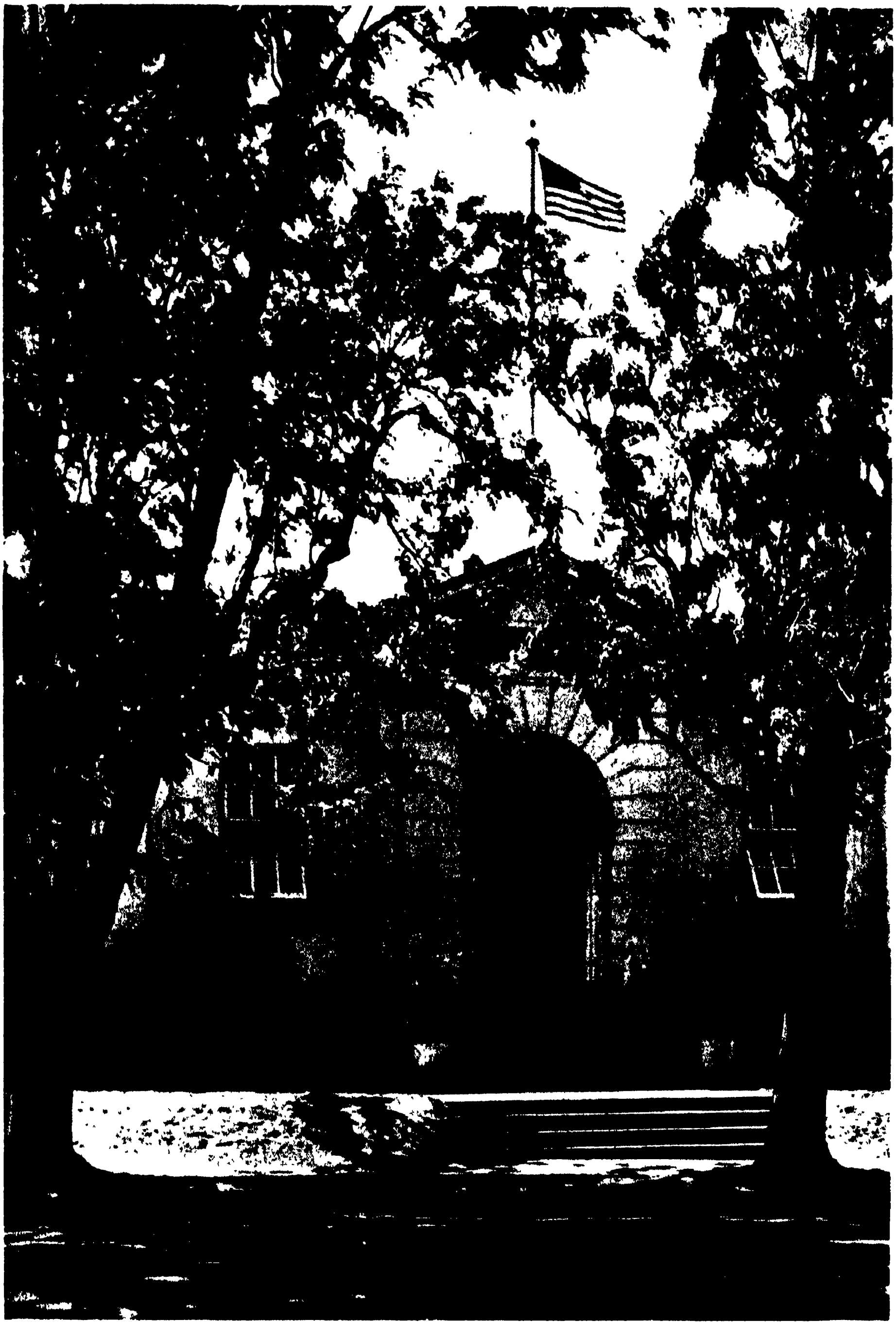
# ILLUSTRATIONS APPEARING ON THE COVERS OF VOLUME XLVIII

## FIRST QUARTER

Sugar cane seedlings of the "44" series in the Makiki greenhouse. Twelve years ago 32-8560 was germinated in this greenhouse—it now occupies 97,000 acres.

# SECOND QUARTER



# THIRD QUARTER

Dr. O. H. Swezey, Consulting Entomologist, who on August 12, 1944, completed forty years of invaluable entomological service to the H.S.P.A. and the Territory as a whole. His work has gained wide recognition not only in Hawaii and on the mainland, but also amongst entomologists all over the world. Today his contributions to the science of entomology continue with unchanged quality and volume.

## FOURTH QUARTER

H 32-8560

# THE HAWAIIAN PLANTERS' RECORD

Vol. XLVIII FIRST QUARTER 1944 No. 1

*A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.*

## Our Field Testing Program*

By R. J. Borden

The extent of the decline in the number of replicated field tests which are now in progress on our plantations is somewhat discouraging to those of us who are charged with the application of scientific methods to studies of the everyday field operations, and with the determination of the relative efficiencies of different agricultural practices. The possible effects from such a reduction in field-test activity upon the future of our agricultural progress should receive our fullest consideration at this time.

We all know that labor-saving devices and techniques are of paramount importance in today's agriculture. There are many individual opinions but fewer facts to support some of the current field practices. A scientific analysis of the factors involved should provide facts now which will still be valuable after the war. This is not the time to "stand by."

It has been the policy of your Association to depend largely on the plantations for cooperative assistance in the field testing of problems which can only be satisfactorily studied through comparisons made in the fields. We believe that now, more than ever, there is a need for the continuance of this cooperation in our research, especially in connection with the everyday or ordinary field operations. How else, for instance, are we to get maximum returns from 32-8560 until we know what gaps in stand it can tolerate without replanting, its capability of enduring variations from a complete weed control, its nitrogen requirements, its maximum irrigation interval and how long it can be "dried off" before harvest, its optimum age for harvest, and what interval it will stand between cutting and milling without severe loss through deterioration? How else are we to know whether some of the changes we have been forced to make in our field practices during the past two years are efficient enough to warrant their maintenance after the war. It will be very easy to get into some bad agricultural habits during these trying days—habits which we may tend to continue after the war, and because we have made so many changes it is going to be very difficult to differentiate between those procedures which are actually efficient and those which are mistakes, unless we get busy now and get the facts. Furthermore, it is not at all unlikely that still more changes in some of our field practices might be made, with resultant savings in man-days of labor and without causing a reduction in sugar yields. I would like to elaborate just a bit along these lines, in hopes that someone of you will find a thought worth further consideration that might be applicable to at least some part of your plantation area. But first let me refresh your memories just a little.

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* As presented at the 63rd Annual Meeting of the H.S.P.A. on December 6, 1943.

Not so many years ago plantations on the island of Hawaii bought and applied many tons of lime to their fields. Repeated tests by field experiments proved that this lime had no beneficial effects on sugar yields, and today there is practically no liming of acid soils being done.

The ineffectiveness of "cutting back" was proved in your field experiments, and this field operation which was quite common at one time has been dropped. The same can be said of the old practice of stripping.

Hilling up and off barring were common field practices until the field tests continued to show that they did not increase sugar yields and, though perhaps not quite as common, we find considerably less subsoiling being done today because, except for a few abnormal areas, the experimental evidence secured from field tests has not shown this operation to be essential.

Ten years ago I made a survey of fertilizer practices which showed medium-to-heavy applications of phosphates being made to both plant and ratoon fields. Repeated field tests have in general failed to show a profitable response to phosphate on those old lands which have been continually in cane since then, and the amounts of this plant food that are being applied today have been greatly reduced and in many cases actually stopped.

Finally, it wasn't so long ago that we spent a lot of time and money to return filter cake to our fields, and it is my guess that we would still be doing this if the experimental evidence had not convinced us that we were not getting any more sugar and were having to harvest a lot more cane when we applied filter cake. So from an economical standpoint we are today disposing of our filter cake in the cheapest way possible.

* * * * * * *

But to proceed: Let's take a look at the way we are growing our 32-8560 and 32-1063, and the results say that we are doing a pretty good job of it too. But can we afford to rest on present results; can't we do a still better job? For instance: do we know what minimum amount of preparation is required for these new canes?

On irrigated lands, the deep plowing that is now done so that the cane lines will hold up through the following ratoons is not so essential since we have developed such efficient line reshapers to fix up ratoon fields. And then too, our present harvesting methods break down these lines to such an extent that it is necessary to build up new lines for ratoons before we can get the water on.

On many of the unirrigated lands, I still wonder why we plow at all. If plowing is done for the purpose of loosening a compacted soil, letting in air and water, then we need to know that sugar yields would be reduced if we did not do such plowing. If it is for the purpose of deepening the soil to allow for an extended root zone, then a sub-surface implement will do an adequate job. If it is for the purpose of burying surface trash and stubble, then we need to know the effects on the nitrogen economy which buried trash will have—for in the decomposition of this organic material the soil organisms are going to use up some of the available nitrogen. If it is to bury the weed seed, then we should give thought to ways and means of destroying the weed seed as it is left on or near the surface of the soil instead of burying it deeply, and then having it come to life whenever we turn over the soil again.

Then we have the question of "What width of row is desirable for these new canes"? If we were to increase the distance between cane rows from 4½ to 5½, or from 5 to 6 feet we would have a good quarter of a mile less of cane rows on each acre. This would take less seed to plant, fewer lines to irrigate, to fertilize, and to cultivate or spray. You can easily see the possible savings in man-days needed to operate such acres—and right here is a possible labor-saving device.

I can already sense your objections to this suggestion. You will say that the wider rows will be slower to close in and so will give you still more weeds to fight. This may be true as far as the interline is concerned in plant fields, but since stands of 32–8560 tend to be thicker and more dense within the cane row when they get the added light which wider rows will give them, there should be even fewer weeds in the cane line where it is always more difficult to control them. And the extra growth between the rows should not add much to the actual weed nuisance.

Your objections on the basis that present equipment is standardized, is also overruled, for we have changed and will continue to change our equipment to make it do the job we want done.

*But,* will yields be adversely affected by these wider rows? Only the replicated field test can answer this. So let's get the facts before we start raising too many objections.

Next comes the ever present problem of weed control. No field operation is getting more attention these days. It's a problem that has always been with us, and it probably will always bother us to a greater or less degree. The chances are very remote that we can eliminate weeds in plantation-scale agriculture—hence our efforts will continue to be in the direction of reducing their detrimental effects by using the cheapest methods we can devise for an effective control.

That great progress has been made in weed control is not denied, but we must go further, for there are still too many man-days for hand hoeing being charged against our cost of production. So we ask this question: What *degree* of weed control is necessary in our 32–8560 and 32–1063 fields? At present we find great differences in this respect; at one place, control is started while the weeds are still in their cotyledon or not beyond their four-leaf stage; at another place the weeds are not touched until they reach their seeding stage. At many places it is still the practice to put in a final weeding just before the cane goes down. We are still not convinced that this final weeding is an essential one in 32–8560 fields, unless of course the weeds are of the viney types or climbers like honohono, hilahila, etc.;

for we believe that if the weeds are controlled sufficiently early to prevent them from shutting light away from the seed bed or ratoon stubble, then the weed nuisance, which is closely tied up with the density of weed growth, will be relatively ineffective on final sugar yields. Furthermore, when the stalks get their growing points above the common annuals and grasses, the weeds will have very little effect on subsequent cane growth of these new fast-growing varieties. We have the results from some of our skirmish tests to support this viewpoint. Thus, weeds starting with plant cane which were *not controlled at all* reduced the yield of 12-month cane by more than 70 per cent. When weed control was neglected for the first six weeks, the loss averaged 45 per cent even though full control was maintained thereafter. When no weeds were allowed to grow during the first six weeks, but weed growth thereafter was not controlled, the loss was only 25 per cent. Where there were no weeds allowed to develop in the first six weeks, and a weed crop which started then was brought under control six weeks later there was no loss in cane or sugar yield from 31–1389 cane. We recognize that these results were obtained in pot cultures and that the same degree of loss might not occur in field practice, but we *do* believe that they indicate the direction our weed control efforts should take, i.e., get the weeds early, and if they do get out of hand after the cane is waist high, take your loss and use your labor on fields with younger cane where it will bring better returns. All this needs proof in the fields however, and the only way to get it is through the field experiment.

Another thing, excepting the climbing weed types, the greatest damage done to a crop of cane by weeds is probably done before the weeds have matured, and this damage is chiefly the result of shading and thus limiting or preventing the stooling. If you fear that the weeds have robbed the cane of nitrogen, and they *will* get some of it, this can quite easily be returned with an application of fertilizer carrying 20 to 30 pounds nitrogen per acre.

In connection with this discussion of weed control, I must mention the recent practice of sub-surface fertilization, which among other virtues places the fertilizer below the root-feeding zones of most of the surface-feeding weed roots, but still not out of reach of the rapidly developing crop roots. In our more common practice of surface application of soluble fertilizers, we make it too easy for the weeds to get their food, and they take full advantage of our generosity. By putting the first fertilizer application well down under the seed, or deep in the subsoil groove alongside ratoon stubble, it will be positionally unavailable to most of the weeds, but the cane roots will reach it quickly, and cane growth will be stimulated and pushed right ahead of the weed growth.

Are you afraid that it will be lost, if it is placed too deep; that it will be leached too far down? We have tried rather unsuccessfully to leach ammonium sulphate below the 6-to-12-inch soil levels, even on acid soils. Although we *can* leach a nitrate nitrogen through many of our soils, in actual usage we probably do not do so, for if we did, we would find a difference in the efficiences of nitrate and ammonia nitrogens—and we don't find this difference. Hence even though a nitrate form of nitrogen can be moved downward by soil water, either from heavy rainfall or heavy irrigations, the fact remains that it is probably not actually lost to the cane crop. Isn't this suggested sub-surface fertilization worthy of your attention in field tests, since we don't know what its effect might be on sugar yields?

Next, how about a practice of alternate row cultivation? Under conditions of extreme labor shortage, some means must be found to spread the available labor over as many essential field operations as possible. The use of a practice of alternate row cultivation for 32–8560 fields occurs to us as one which might be studied for its effect on final yields. Thus on irrigated lands, weed control operations would start with a broadcast spraying. Thereafter, mechanical cultivation or knapsack spraying would be confined to alternate rows, keeping one row-middle free of weeds until the crop has established its stand. Fertilizer would be placed in the center of this clean row-middle, and should feed the two adjacent lines of cane. Naturally this practice could not be used on fields where honohono and climbing weed types persist.

On the irrigated lands one might also consider putting fertilizer on alternate cane rows. Our studies of border effect in field tests have suggested that this might be done without a very serious reduction in yields of the alternate unfertilized row. Furthermore, on soils which have good lateral seepage, we might irrigate only every other line, and alternate the irrigated row in every other round; such a procedure might be well adapted especially to hilled-up ratoon fields. If it could be proved that such methods did not reduce sugar yields, it goes without saying that they would increase man-day performance and grow cheaper sugar. However, they are not procedures to be adopted without checking in replicated field tests on such of your fields where they may have a reasonable chance of succeeding.

Then we have the nitrogen problem. Questionnaires returned to the Genetics department recently recorded an overwhelming opinion that 32–8560 needs less nitrogen than other varieties. How do we know? I think so too, but honestly, do we have the facts? I have a strong suspicion that we can get better quality from 32–8560 which is scheduled for fall harvesting if we hold its nitrogen supply down —perhaps to not more than 100 or 125 pounds—and put it on early, for there is less and less evidence that there is anything to be gained from holding back some nitrogen for a second-season application (at 11 or 12 months). I might go even further and ask "why can't we apply *all* of the nitrogen in one or at most in two applications? Are we afraid that it will be leached away if the applications are too large?" It may be that we have become unnecessarily concerned about the loss of soluble nitrogen fertilizers by leaching. All right then, why not a single fertilizer application located 8 or 10 inches below the surface when the crop is started? Here's a labor-saving idea, but will it decrease the sugar yields? Let's get the proof!

Should we plan now to grow only plant crops? Look for a minute at these figures which we have taken from some of your actual field records:

| | Tons sugar per acre per month (TSAM) | | |
|---|---|---|---|
| Field | Plant crop | 1st ratoon | 2nd ratoon |
| A-2 ................ | .54 | .44 | .31 |
| A-4 ................ | .50 | .35 | .33 |
| 2-B ................ | .60 | .50 | .42 |
| 9-A ................ | .62 | .53 | .37 |
| 9-B ................ | .56 | .34 | .36 |
| 2-A ................ | .58 | .51 | .40 |
| 0-7 ................ | .66 | .54 | .49 |

I have many more just like them and your field records will show you similar ones. What do they mean? From field data recently submitted to the Genetics department we have found this same sort of decline in TSAM from 32–8560 first ratoons. For example, 19 out of 22 fields reported, showed an average loss of .08 TSAM for the first ratoon over the plant crop, with 16 of these fields showing a loss for ratoons of more than one ton of sugar per acre. In these same fields, during their previous cycle with the variety that 32–8560 has replaced, the corresponding average loss for the first ratoon over the plant crop was .04 TSAM, so we have little reason to believe, at this time, that the decline in ratoons of 32–8560 will be materially different from that of former varieties.

At a loss of one ton of sugar per acre, we have the equivalent of a loss of about $40.00 before harvesting. Therefore, if it costs less than $40.00 an acre to bring plant crops to maturity than it does to mature ratoon crops—and I am sure that there are many fields where this would be true—then it can be quite uneconomical to grow ratoons on such fields. And if only plant crops were to be grown, there are many modifications of our field practices as now used that could be made which would still further reduce the cost of plant crops. Finally, in those cases where man-day requirements are apt to be lower in plant fields than in ratoons, such benefits will be gratefully accepted too.

I could continue to ask questions like these; questions that we frequently ask ourselves, and for which we do not have reliable answers; answers that would be valuable right now if we had them. We won't get them by a policy of dropping experimental work "for the duration." We won't be fully ready for the post-war competition with South American sugar if we put off our testing of these problems until the war is over. We need a re-evaluation of the field experiment today, for our cooperative field research has almost come to a stop. Won't you give it its share of your labor and attention, and help us to help you get the facts?

# Elongation of Grain in Low-grade Massecuites

Compiled by W. L. McCleery

The long-recommended size of low-grade massecuite grain, boiled from normal quality material, has been a length of from 0.25 to 0.35 mm. when ready for the crystallizer. The usual width of such grain is about from 0.10 to 0.15 mm. At a few factories the width is proportionately larger and but slightly less than the length. An even grain, within these dimensions, is the minimum size that will purge well in the centrifugals and presents a maximum of crystal surface for the rapid reduction of mother liquor purity, without danger of forming false grain.

It has been noted for a long time, at many factories, that there are periods, usually of short duration, when the grain elongates without increasing in width, *i.e.*, grows only in length, and usually very slowly at that, so that the final dimensions may be only 0.05 mm. or less in width by perhaps 1.00 mm. long. This needle-shaped grain does not exhaust the molasses, frequently breaks up in the pan and the crystallizers and always tends to clog the screens in the centrifugals. Such strikes usually have to be finished at low density and the result is that the purity of the final molasses is high and the quality of remelt sugar is poor in the majority of cases.

Recently the California and Hawaiian Sugar Refinery staff reported that they were having trouble with a more or less similar type of grain in their second and third remelt strikes.

We have long known that periods of needle grain in low-grade massecuite have been associated with grinding soured cane resulting from any one of a number of causes; that in spite of any modifications in process procedure, very little could be done about it in the factory and that it served as a direct indicator that there were irregularities in the field or in the harvesting procedure.

We have rapidly changed cane varieties and harvesting methods in recent years, and had an acute shortage of plantation labor since some time "before Pearl Harbor," and as C. & H. Refinery was having trouble with its low-grade material, it was thought advisable to make a survey. Letters were sent to the manager of each factory asking that a member of their staff give us their experiences and opinions concerning needle grain. The letters contained a list of 23 questions covering various phases of the problem, particularly toward obtaining opinions as to causes, prevalence, and extent of difficulties encountered, the remedies tried and results. All but two factories of the 34 gave us complete reports. The questions and summary of the answers are listed below.

1. Is slow-boiling low-grade massecuite usually accompanied by long so-called needle-shaped grain?

The majority opinion is that slow boiling is not necessarily accompanied by the formation of needle grain.

2. In reverse does this long grain always boil and grow slowly?

The true needle-shaped grain nearly always grows slowly and the massecuite is classed as slow boiling.

3. *Possible Causes of Long Grain:* Does long grain come from poor clarification?

Poor juice clarification, as such, is not considered an indicator of needle grain in final massecuite. See, however, question No. 14 concerning honohono grass.

4. From certain cane varieties? 5. From certain field areas? 6. If from certain fields, are these situated so that harvesting is slower than normal? 7. From overage cane?

The answers to these questions were generally *no.* However, there is a firm opinion held by some that certain varieties, especially under makai land conditions, do not carry over well to the time of harvest. Certain mauka lands have also been mentioned. The explanation given is that many of the older or primary stalks die and the juice becomes sour or that souring is induced by cane borers working in stalks that are wholly or partially dead. Soured cane from any cause is considered to be the principal cause of needle grain.

8. Sour cane, from accidental fires? 9. From cane burned or harvested with too long an interval before grinding in dry weather? 10. From delayed grinding after burning or cutting, due to wet weather?

The opinion is almost unanimous that the amount of souring, under any of these conditions, is a reliable indicator of the severity of trouble that will result from needle grain. Several reports mentioned that souring is accelerated by wet weather after harvesting, particularly so by alternate periods of showers and hot sunshine.

11. From untopped cane? 12. From mechanically harvested cane?

Neither untopped cane nor mechanically harvested cane, as such, is thought to be a cause of needle grain. Mechanically harvested cane, however, has a great many stalks that are crushed, split and broken that will sour very readily, hence should be ground more quickly than cane harvested in the old manner.

13. From trashy cane with much field soil? 14. From trashy cane containing weeds and grasses?

The opinions on these two questions were fairly evenly divided. There were several replies which emphasized that decomposed field trash was a contributing factor. Several others reported that cane containing large amounts of honohono grass when ground gave poor clarification and was a cause of needle grain. We know that juice expressed from honohono grass alone does not clarify by any of the usual methods.

15. Is flumed cane with most of the soil removed less troublesome than·non-flumed?

Answers from several of the factories grinding flumed cane indicate that fluming is an advantage in that dead cane is (partially) rejected by the men at the flumes.

16. Has juice purity, high or low ash or high or low glucose any apparent affect?

The analysis of the juice is not an indicator, except that it may reflect decomposition or souring as shown by low purity or high glucose. An unripe cane juice of 80 purity will not give the trouble that juice from ripe cane of 86 will, if it has soured to 80 purity.

17. Rough percentage of the days of crop year when long grain is bothersome?

About 50 per cent of the answers did not give an estimate, yet many of these stated that they were bothered by needle grain but had no definite data. The figures from 15 factories giving percentage estimates ranged from 3 to 40 per cent as follows: 25, 10, 15, 20, 40, 4, 5, 30, 13, 5, 20, 12, 3, 8, with an average of 15 per cent. The factories reporting high figures were Wailuku 30, Onomea 25, Kaiwiki 20, Paauhau 40, and Kilauea "not over 20 per cent." Five factories reported no needle grain or that it gave no trouble: H. C. & S., Waiakea, Hakalau, Hamakua and Lihue.

18. Is purging time of low-grade affected?

All factories reported slower purging massecuites, except the 5 who reported "no trouble."

19. Purity of low-grade sugar lower, by how much?

Twenty-two factories reported that sugar purities were reduced from 3 to 11 points when purging needle grain. The average is 6.0 points.

20. Purity of final molasses higher and by how much, during bad periods?

Twenty-four factories gave figures ranging from 1 to 6 points higher, with an average of 4.0.

21. Has any treatment of "B" molasses by soda, lime or otherwise, or modification in clarification procedure helped?

The majority report that no treatment tried has been effective. A few report that soda ash, added to the B molasses or introduced in the pan before graining, improves the boiling. One reports that running an "acid house" helps and another "reduced the pH." Kohala factory obtains "freer boiling and faster graining massecuites by adding soda ash to the clear juice from the secondary Dorr before it goes to the primary Dorr." Pioneer states that "if the juice is partly neutralized with soda before liming it will help slightly." Oahu and Ewa factories do not lime sour juices to the usual pH, to avoid using an excessive *amount* of lime. They reduce lime salts and build up the pH of the clarified juice by substituting soda ash for part of the lime.

22. Does long grain appear with no apparent cause?

Nearly all have very firm opinions as to the cause, *i.e.*, deteriorated juice in the cane, either before or after burning, or after harvesting. Grinding large amounts of decomposed leaves and "dead" cane are thought by some to be strong contributing factors.

23. Does long grain give more trouble now than 5 to 7 years ago?

The majority believe that they are now having more trouble than formerly. More cane is being damaged which makes it subject to rapid fermentation. Paauhau factory reports less trouble "due probably to a change in varieties" that carry over better.

## SIDELIGHTS

Many factories submitted some very interesting remarks of which the following are a few excerpts:

*Oahu:*

Many years ago at the Oahu Sugar Company we came to the conclusion that sour cane and excessive trash were the cause of long-grain crystals. This contention was borne out by the fact that the long crystal invariably appeared in the pans after a rainy spell when field burns were poor, or the harvesting crews were unable to bring in the cut or burned cane on schedule, resulting in a high proportion of sour cane.

With the present harvesting methods where the cane is . . . [damaged], there is always present a small amount of sour cane. Mechanical harvesting is responsible for this but, with reasonably good field burns, this condition need not be serious providing the cane reaches the factory . . . [quickly].

Last year and the present year especially are very abnormal years . . . labor difficulties have thrown harvesting schedules all out of line, with the result that fields are overage at time of harvest. Two important factors enter the picture here and, unfortunately, both are equally bad. We have an excessive amount of dead cane and a high percentage of immature suckers entering the factory. Taken together, they both tend toward higher total lime in the mixed juice which our pH control does not indicate. Overliming, plus the non-sugars necessarily introduced by the above cane conditions, are the chief causes of slow boiling. Soil particles carried over in the clarified juice will likewise slow up boiling, but this is purely a question of fouled-up heating surfaces.

*Honolulu:*

1. During the 3 weeks we ran the refinery alone in August 1943 we had long grain for the total period.

2. In order to dry massecuites with long grain it is necessary to dilute the low-grade massecuite.

3. This month, when grinding cane from Waipahu which was 25 months old and hadn't been irrigated for almost a year, we had long grain and at the same time purities were low.

*Ewa:*

There are four different shaped crystals common in low-grade. They are as follows: 1. The square crystal. 2. The crystal with two corners off. 3. The rectangular crystal. 4. The triangular crystal.

The first two crystals are common at Ewa, with the square crystal holding the edge, and are the two easiest crystals to work with.

The rectangular and triangular crystals usually appear when the cane has become too dry or has become deteriorated. These crystals are hard to work with, the massecuite in both high- and low-grade strikes boils slowly, and great care has to be exercised to keep out false grain. The latter of these two crystals is usually accompanied in the massecuite with an abundance of lime salts. The pan drop from massecuite to molasses is not normal when either of the above types of crystal are present, and it is practically impossible to approach anywhere near the expected final molasses gravity purity.

*Waialua:*

At no time during the 1943 season did we get real needle grain but very often we did get grain about 3 to 4 times as long as wide. Our experience is that only sour juice will produce long grain. The sourer the juice the longer the grain.

*Maui:*

We believe long grain to be due to damaged cane, either in growth, as by exposure to salt spray, drying out, insects or fungus, etc., or to damage afterward, as burning too long before harvesting, delay in grinding, etc.

*Pioneer:*

With us, at least, the conditions which produce needle grain are always brought about by some abnormal field situation. Deterioration of the cane, due to age; sour cane which sometimes occurs when weather interferes with loading; machine cane badly mangled which has bled badly and become sour; and too long a time between burning and grinding.

### *Kilauea:*

As a rule we encounter excessive long grain when we are grinding trashy and grassy cane from poorly burned fields. At times we get long grain for no apparent reason, but on checking we usually find that the cause is from cane that has been cut for about 24 hours and subjected to intermittent showers and hot sunshine. On the other hand cane in the same field may be 24 hours older and not cause long grain if the weather is constant. It seems that dampness and heat have a tendency to increase the rapidity of inversion.

### *Paauhau:*

We have found it [needle grain] due to deteriorated cane or ''dead'' trash.

We have observed needle grain at this factory since 1930 and have found graining methods that produce ''square'' grain in other locations to be of no effect when handling deteriorated material. Our cleaning plant has been a help in that it removes most of the ''dead'' trash.

Our observations have been as follows:

1. Agitation of low grade massecuites while boiling increases elongation of grain; consequently we do not start the mechanical circulator in our low-grade pan until it is about ⅓ full.
2. When the initial grain is well formed, it will elongate if the molasses boiled in is from poor quality cane; also, poorly formed initial grain may correct its form if good quality molasses is boiled in.
3. Increase of purity of graining charge aids at the beginning, but the purity of the completed strike determines the amount of elongation with a given material.
4. Low supersaturation boiling in early stages of strike and ''closing'' the strike by boiling on water does not affect final results.
5. The tendency in our case has been for needle grain to increase after about the first of August, when juices have passed their ''peak'' stage.

### *Hutchinson:*

When boiling massecuite of high viscosity we find that long grain only appears when boiling low-purity syrup or molasses from sour cane, especially when grinding dirty sour cane containing tops and other field trash.

We have noticed that boiling conditions and grain quality improves when the period between cutting or harvesting and grinding is favorable, say 48 hours or less.

### *Pepeekeo:*

Some observations noted on juices that produce needle grain:

Pan boiling time doubles. Always subject to the formation of a secondary mass of needle grain upon concentration of massecuite. Nearly impossible to wash out, as the original grain melts before the needle grain. In most cases washing increases the difficulty.

In seeding low-grade pans the grain first appears normal and square; upon concentration it becomes elongated. Further concentration brings out additional fine needle secondary grain. In a few rare cases it has been almost impossible to start a seed in a graining molasses.

Drying low-grade in some cases would be impossible except for excessive overheating of the massecuite. Greatest trouble is the molasses forming on the inside of the centrifugal basket. Sugar would be well dried behind a layer of molasses sometimes thicker than the layer of sugar.

The writer wishes to thank the managers for their cooperation and the factory staff members who prepared their very complete reports for us.

# Cumulative Effects from Heavy Applications of Nitrogen Fertilizers

By R. J. Borden

*Although different sources of nitrogen used in the fertilization of sugar cane on irrigated soils will have different cumulative effects on the pH of the soil, and may also affect the solubility of some soil minerals, it has not been convincingly proved, after ten years of excessively heavy applications, that cane or sugar yields are differentially influenced by these changes in the soil.*

* * * * * * *

Whenever a group of sugar cane agriculturists get into a discussion about the relative merits of ammoniacal and nitrate nitrogen fertilizers, and listen to the ammonium-sulphate advocate cite instances of actual loss of nitrate of soda nitrogen through leaching, and to the nitrate-of-soda advocate quote proof of conditions of practically soil sterility caused by the cumulative residual acidity from ammonium sulphate, some bright individual is always prepared to throw in the comment—"so what"! Thus it was, following just such a discussion in 1932, that J. A. Verret proposed that we set up a test* to determine the effect that continued heavy applications of different nitrogen fertilizers to an already acid soil would have upon cane yields and its quality and sugar recovery, since these were the important measurements that would have real meaning to the planters. Coincidentally a study of some of the effects which these large applications of fertilizer would have on soil and plant composition might supply data which would be useful in interpreting any yield differences which would be secured. It is ten years since the original crop was planted and the results from the nine crops harvested during this first ten-year period can now be summarized.

## THE PLAN

The soil selected was a residual yellow-brown silty loam from Manoa, Field 22, with an excellent granular structure and organic matter content which makes it well-drained. A composite field sample analyzed by our Chemistry department was reported to have the following composition:

| 1% Citric Soluble | | | | | Water Soluble | | | | |
|---|---|---|---|---|---|---|---|---|---|
| pH | $SiO_2$ | CaO | $K_2O$ | $P_2O_5$ | $SO_3$ | Na | Al | Cl | Fe |
| 5.3 | .183 | .037 | .009 | .011 | .0025 | .0025 | Trace | .009 | .011 |

A large stock of this soil was thoroughly mixed and then transferred to large 2'x2'x2' concrete pots (Fig. 1), the insides of which had been well coated with asphalt. In filling these pots the soil in the lower halves was firmly tamped before the upper layers were put in, thus the soil conditions in these containers were made more comparable with those of the field. Careful estimates, and volume weights made later on, place the amount of soil per pot at approximately 420 pounds.

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* Project A-105—No. 33.

Although the citric-soluble soil analyses had indicated no real deficiency in phosphate, a heavy application of superphosphate was made under the seed at time of planting.

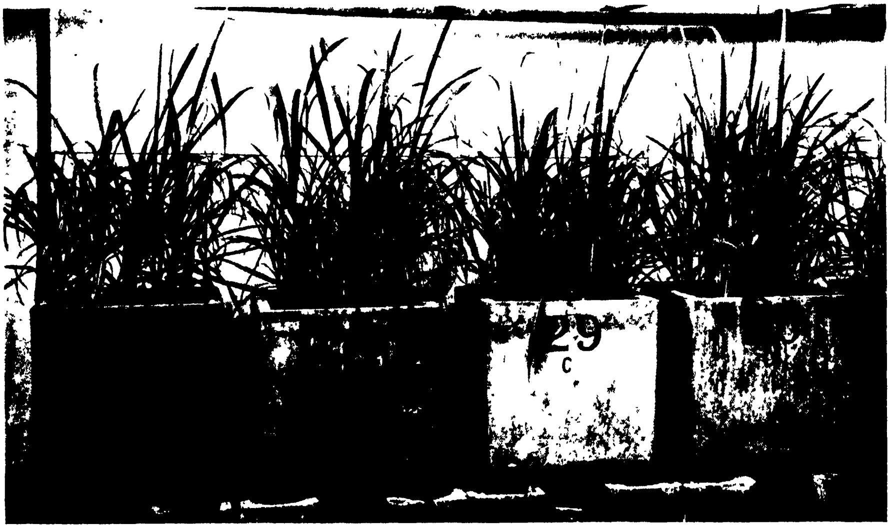

**Fig. 1.** The tenth crop of sugar cane (now 31-1389 third ratoons) at age of 5 weeks, growing in the 2'x2'x2' concrete containers which were originally filled with Manoa soil in 1933 and to which nitrogen from different sources (see text) has subsequently been applied in an amount equivalent to a total of 9,000 pounds of N per acre.

Cuttings of the cane variety POJ 36, carrying eight good eyes, were planted on June 5, 1933 and, as soon as a good selection could be made, the stand was thinned to four primary stalks per pot; thereafter no attempt was made to control the stooling. Similarly, for each ratoon crop grown, we have attempted only to see that the crops were started off with comparable stands in all pots.

The cane crops in these large containers have at all times received adequate and sometimes excessive irrigation, and during periods of heavy rainfall the excess waters with whatever solutes they contained have been carried away through the drainage holes two feet below the surface of the soil in the pots. Since the pots were set up at Makiki, it has been necessary to use Makiki tap water for irrigation and this, like most of the pump waters used for irrigating sugar cane lands, has an alkaline reaction (pH 8.1–8.3) which probably has had some effect on the soil reaction.

Fertilization of each crop was specifically planned so that excessively large amounts of three different nitrogen fertilizers would be applied to the relatively small volume of soil in each pot; the basic idea was to learn as quickly as possible whether such large amounts would eventually ruin this soil for satisfactory sugar cane growth. Hence it was planned to give each pot nitrogen at the rate of 1000 pounds per acre for each crop to be grown. Three sources of nitrogen were chosen —ammonium sulphate, nitrate of soda, and urea. In addition it was decided to check the results from ammonium sulphate when the total amount for each crop was given in a single vs. several applications. Thus four treatments were installed and are identified as follows:

| Treatment identity | Source of N | Number of applications per crop |
|---|---|---|
| A | Ammonium sulphate | In one application at 4 to 6 weeks. |
| B | Ammonium sulphate | In 4 applications at 2-month intervals. (*Note:* After the third crop this was changed to 5 applications at 6-week intervals.) |
| C | Nitrate of soda | |
| D | Urea | |

All pots received identical and adequate amounts of both potash and phosphate for each crop grown.

## THE RESULTS

In Table I we give some of the pertinent data taken from the nine crop "logs."

TABLE I

CROP HISTORIES

| Crop year | Variety | Crop | Planted | Harvested | Age (mos.) | Fertilization grams per pot N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|---|---|---|---|---|
| 1934 | POJ 36 | Plant | 6/5/33 | 11/15/34 | 17.3 | 42 | 42 | 42 |
| 1935 | POJ 36 | 1st ratoon | 11/16/34 | 11/26/35 | 13.3 | 42 | 21 | 21 |
| 1937 | POJ 36 | 2nd ratoon | 12/27/35 | 3/31/37 | 15.0 | 42 | 21 | 21 |
| 1938 | POJ 36 | 3rd ratoon | 4/9/37 | 4/21/38 | 12.3 | 42 | 21 | 61 |
| 1939 | POJ 36 | 4th ratoon | 4/22/38 | 4/18/39 | 12.0 | 42 | 21 | 61 |
| 1940 | POJ 36 | 5th ratoon | 4/19/39 | 5/7/40 | 12.6 | 42 | 20 | 100 |
| 1941* | 31–1389 | Plant | 6/17/40 | 7/2/41 | 12.5 | 42 | 20 | 100 |
| 1942 | 31–1389 | 1st ratoon | 7/3/41 | 6/29/42 | 12.0 | 42 | 40 | 100 |
| 1943 | 31–1389 | 2nd ratoon | 6/30/42 | 6/28/43 | 12.0 | 42 | 40 | 100 |

* After the 1940 crop was harvested the old POJ 36 stubble was removed, the surface foot of soil was loosened up and turned over, and the pots replanted with the variety 31–1389 after only 6 weeks of fallow.

TABLE II

CANE AND SUGAR YIELDS

| Crop year | Average pounds of cane —treatment— A | B | C | D | Min. diff. req. | Average pounds of sugar —treatment— A | B | C | D | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1934 ...... | 52.8 | 55.6 | 51.9 | 49.6 | 4.4 | 7.41 | 7.99 | 7.35 | 7.33 | |
| 1935 ...... | 35.8 | 40.4 | 41.0 | 37.8 | ns | 4.75 | 5.40 | 5.56 | 5.12 | ns |
| 1937 ...... | 28.3 | 36.8 | 35.8 | 33.8 | ns | 3.62 | 4.56 | 4.74 | 4.58 | ns |
| 1938 ...... | 21.6 | 32.4 | 32.0 | 26.4 | 3.9 | 2.94 | 4.27 | 4.29 | 3.54 | .54 |
| 1939 ...... | 28.4 | 33.3 | 33.8 | 31.1 | ns | 3.63 | 4.08 | 3.97 | 4.20 | ns |
| 1940 ...... | 34.5 | 35.7 | 32.0 | 35.7 | ns | 4.91 | 4.10 | 3.83 | 4.19 | ns |
| 1941 ...... | 71.3 | 63.0 | 64.1 | 56.9 | 8.0 | 10.78 | 8.78 | 9.18 | 8.55 | 1.13 |
| 1942 ...... | 48.7 | 51.0 | 52.6 | 47.7 | 3.3 | 6.73 | 6.28 | 6.65 | 6.00 | ns |
| 1943 ...... | 48.6 | 57.7 | 56.4 | 52.7 | ns | 7.38 | 7.90 | 7.66 | 7.35 | ns |
| Total for 9 crops .... | 370.0 | 405.9 | 399.6 | 371.7 | — | 52.18 | 53.36 | 53.23 | 50.86 | — |

ns = difference not significant.

*Yields:* In Table II a summary of the cane and sugar yields is shown. The crop figures are averages from four replicates, and where the treatment effects were statistically significant, the minimum difference required (for P at .05) is also given. These yield data show quite convincingly that (1) there has never been any significant difference in the effect on yields between ammonium sulphate and nitrate of soda (Treatments B and C); (2) although urea (D) has been slightly less effective than either nitrate of soda (C) or ammonium sulphate (B), this has not been true in all crop years; and (3) yield differences resulting from the use of the ammonium sulphate in single (A) or in split (B) applications have not consistently proved the superiority of either practice.

The average cumulative yield of cane harvested from all treatments for this ten-year period was 387 pounds of cane per container. An equivalent field yield would depend upon how it is calculated, *e.g.*, (*a*) if based on the actual surface area of each pot (four square feet) the cumulative yields would be comparable with 2107 tons per acre or with twenty-one 100-ton crops; (*b*) if based on the actual weight of soil in each pot, it would amount to roughly 1150 tons per 2½ million pounds of soil, or to eleven 100-ton crops from an acre of soil one foot deep; and (*c*) if based on the maximum "feet of row" in the containers (two feet) and the assumption of 8712 feet of cane row in an acre in the field, the cumulative yield is 843 tons per acre or the equivalent of about eight 100-ton crops. Take your choice if you insist on a field equivalent!

TABLE III

CRUSHER JUICE COMPOSITION

| Crop year | Yield per cent cane treatment | | | | Min. diff. req. | Per cent nitrogen (N) treatment | | | | Min. diff. req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | | A | B | C | D | |
| 1934 ...... | 14.08 | 14.38 | 14.18 | 14.75 | ns | - | — | - | — | — |
| 1935 ...... | 13.28 | 13.34 | 13.54 | 13.49 | ns | .015 | .025 | .028 | .014 | .008 |
| 1937 ...... | 12.50 | 12.22 | 13.00 | 12.88 | ns | .022 | .026 | .018 | .016 | .007 |
| 1938 ...... | 13.58 | 13.15 | 13.40 | 13.32 | ns | .015 | .027 | .020 | .020 | .003 |
| 1939 ...... | 12.60 | 12.31 | 11.78 | 13.52 | ns | .018 | .029 | .021 | .019 | ns |
| 1940 ...... | 14.26 | 11.52 | 12.03 | 11.72 | 1.77 | .015 | .032 | .021 | .022 | .006 |
| 1941 ...... | 15.16 | 13.95 | 14.34 | 15.04 | .41 | .012 | .014 | .015 | .015 | ns |
| 1942 ...... | 13.82 | 12.33 | 12.64 | 12.59 | ns | .010 | .016 | .018 | .018 | .003 |
| 1943 ...... | 15.16 | 13.67 | 13.56 | 13.94 | .38 | .011 | .016 | .015 | .014 | .004 |
| Avg. for 9 crops .... | 13.83 | 12.99 | 13.16 | 13.47 | — | .013 | .021 | .017 | .015 | — |

| Crop year | % phosphoric acid ($P_2O_5$) treatment | | | | Min. diff. req. | % potash ($K_2O$) treatment | | | | Min. diff. req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | | A | B | C | D | |
| 1934 ...... | — | — | — | — | — | — | — | | — | — |
| 1935 ...... | .011 | .014 | .013 | .017 | ns | .035 | .038 | .038 | .053 | .013 |
| 1937 ...... | .017 | .015 | .016 | .016 | ns | .030 | .020 | .020 | .022 | ns |
| 1938 ...... | .021 | .021 | .023 | .028 | .005 | .155 | .085 | .118 | .128 | .063 |
| 1939 ...... | .035 | .039 | .035 | .042 | ns | .070 | .079 | .070 | .062 | .014 |
| 1940 ...... | .030 | .033 | .034 | .046 | .010 | .080 | .083 | .085 | .085 | ns |
| 1941 ...... | .024 | .030 | .042 | .044 | .016 | .092 | .080 | .092 | .088 | ns |
| 1942 ...... | .038 | .037 | .048 | .063 | .015 | .082 | .080 | .098 | .128 | .022 |
| 1943 ...... | .055 | .052 | .057 | .067 | .003 | .090 | .065 | .070 | .068 | .017 |
| Avg. for 9 crops .... | .026 | .027 | .030 | .036 | — | .070 | .059 | .066 | .070 | — |

*Crusher Juices:* In Table III several crusher juice analyses are summarized for the nine crops harvested from each of the four treatments. From these data we get the following information:

(*a*) Cane quality, as indicated by yield per cent cane, has shown no consistently significant effect from the different sources of nitrogen. Averages for the separate harvests may indicate that cane quality in Treatment B (ammonium sulphate) has generally not come up to the level of the quality from Treatment C (nitrate of soda) or Treatment D (urea) but the differences are not statistically significant. The yield per cent cane from Treatment A (single application of ammonium sulphate) has been somewhat better than from Treatment B (split applications).

The purity figures (not tabulated) were not significantly different for treatments except in 1943 when Treatment A had a definitely higher purity than any of the other three treatments.

(*b*) In the first five crops with POJ 36 cane, the percentages of nitrogen in the crusher juices from ammonium sulphate (B) were generally higher than from the other two sources of nitrogen, but this condition has not been found since the variety was changed for the 1941 crop. We note also that the concentration of nitrogen in the juice at harvest has been less when ammonium sulphate was supplied in a single than when given in split applications.

(*c*) The gradual build-up of phosphoric acid in the juices from all treatments in more recent crops reflects undoubtedly the increased amounts of this nutrient which was supplied in the fertilizers (see Table I). This $P_2O_5$ concentration was generally higher in the cane fertilized with urea. Differences between nitrate of soda and ammonium sulphate were not proved, nor did the single application of ammonium sulphate affect the percentage of phosphate in the crusher juice any differently than did split doses.

(*d*) The percentages of potash in the crusher juices were so low in the 1935 and 1937 crops that potash fertilization for all four treatments was increased for the 1938 crop, and then stepped up again for the 1940 and subsequent crops. Urea produced cane with a higher percentage of potash in juice than either nitrate of soda or ammonium sulphate in 1935 and 1942, but in 1939 the potash concentration of cane fertilized with ammonium sulphate was greater than that from the urea-fertilized cane. No significant differences were noted between ammonium sulphate and nitrate of soda in their effect on this potash concentration. On two occasions the effect of a single application of ammonium sulphate was to increase the per cent $K_2O$ in juice of its cane over that from the split applications.

TABLE IV

AVAILABLE (RCM) PHOSPHATE AND POTASH IN SOIL AT HARVEST

| Crop year | Per cent $P_2O_5$ treatment | | | | Min. diff. req. | Per cent $K_2O$ treatment | | | | Min. diff. req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | | A | B | C | D | |
| 1939 ...... | .045 | .045 | .018 | .046 | ns | .0038 | .0027 | .0029 | .0029 | ns |
| 1940 ...... | .020 | .020 | .016 | .013 | ns | .0035 | .0029 | .0030 | .0060 | .0016 |
| 1941 ...... | .022 | .014 | .010 | .013 | .006 | .0030 | .0025 | .0028 | .0028 | .0003 |
| 1942 ...... | .023 | .022 | .014 | .012 | .006 | .0026 | .0026 | .0029 | .0026 | ns |
| 1943 ...... | .024 | .021 | .018 | .016 | .003 | 0029 | .0027 | .0026 | .0024 | .0002 |

*Soil Analyses:* No significant differences between treatments were measured in the amounts of water-soluble nitrogen found in the soil at harvest. These amounts were seldom as much as ten parts per million and indicate a fairly complete uptake of the heavy nitrogen applications that were made to each crop.

Since 1939 the soil samples, taken with an auger to the full two-foot depth in each pot, have been analyzed by R.C.M. for their available phosphate and potash content. The data in Table IV do not indicate any great accumulation or building up of these available nutrients in this soil. The effects from the different nitrogen treatments indicate more available phosphate to be present in the soil fertilized with ammonium sulphate, but there is little difference between the other two nitrogen carriers in this effect on soil phosphate. The effects on available soil potash are not highly significant except in one instance (1940) when the urea apparently left more potash in the soil at harvest.

## TABLE V
## pH OF SOIL AT HARVEST

| | Soil pH | | | |
|---|---|---|---|---|
| | treatment | | | |
| Crop year | A | B | C | D |
| 1934 ............ | 6.6 | 6.6 | 7.0 | 6.9 |
| 1935 ............ | 6.3 | 5.9 | 7.2 | 6.7 |
| 1937 ............ | 6.1 | 5.9 | 6.8 | 6.7 |
| 1938 ............ | 5.4 | 5.1 | 6.4 | 6.2 |
| 1939 ............ | 5.8 | 5.5 | 6.6 | 6.3 |
| 1940 ............ | 5.0 | 5.0 | 6.7 | 6.0 |
| 1941 ............ | 5.6 | 5.7 | 6.8 | 6.6 |
| 1942 ............ | 5.1 | 4.9 | 7.0 | 6.8 |
| 1943* ........... | 4.9 | 4.6 | 6.2 | 6.0 |

* After harvest of the 1943 crop, soil samples analyzed by A. S. Ayres were found to have the following amounts of exchangeable calcium (Ca):

| Treatment | m e./100 gms | lbs. CaO/acre ft. |
|---|---|---|
| A | 2.43 | 1700 |
| B | 1.85 | 1300 |
| C | 8.78 | 6150 |
| D | 6.55 | 4600 |

Also, the ultimate pH of a composite sample from all four treatments was found to be 4.5.

Perhaps the most significant effect that has been identified in this study is that which the different nitrogen fertilizers have made upon the pH of this originally acid soil during its first ten years of intensive cropping (see Fig. 2 or Table V). We might compare the cumulative effect from the nine 42-gram applications of nitrogen supplied to the 420 pounds of soil in each container, with the use of 9000 pounds of nitrogen from one of three different nitrogen carriers, or sufficient for 45 crops of sugar cane if used at the rate of 200 pounds per acre in the field.

The soil samples were taken immediately after harvest with a one-half-inch auger to the full depth of the two-foot pot, and four borings per pot were composited and prepared for pH and other analyses. Although the original soil at time of potting had a pH of 5.3, its acidity was considerably reduced during the first three years of cropping, regardless of the source of nitrogen used. However, there is little doubt but that the ammonium sulphate has now produced a soil with a lower pH value than either nitrate of soda or urea; also, there is a consistent indication that the soil pH from the urea fertilization has been slightly lower than that from the nitrate of soda. Finally, there is no indication that the soil which has been heavily fertilized with nitrate of soda is becoming increasingly alkaline. In making these comparisons, we are not unaware of the fact that the irrigation water had a slightly alkaline reaction nor that the drainage waters have occasionally "flushed" these soils. Yet in spite of these wide differences in the present pH values of these soils, we have already seen (Table II) that neither the cane nor the sugar yields from this last 1943 crop has been differently affected. Thus it is apparent that sugar cane, grown under irrigation, can be made to produce very satisfactory crops of cane of good quality, even if the soil is or becomes very acid, providing of course that it is adequately furnished with plant nutrients which may be deficient in such soils.

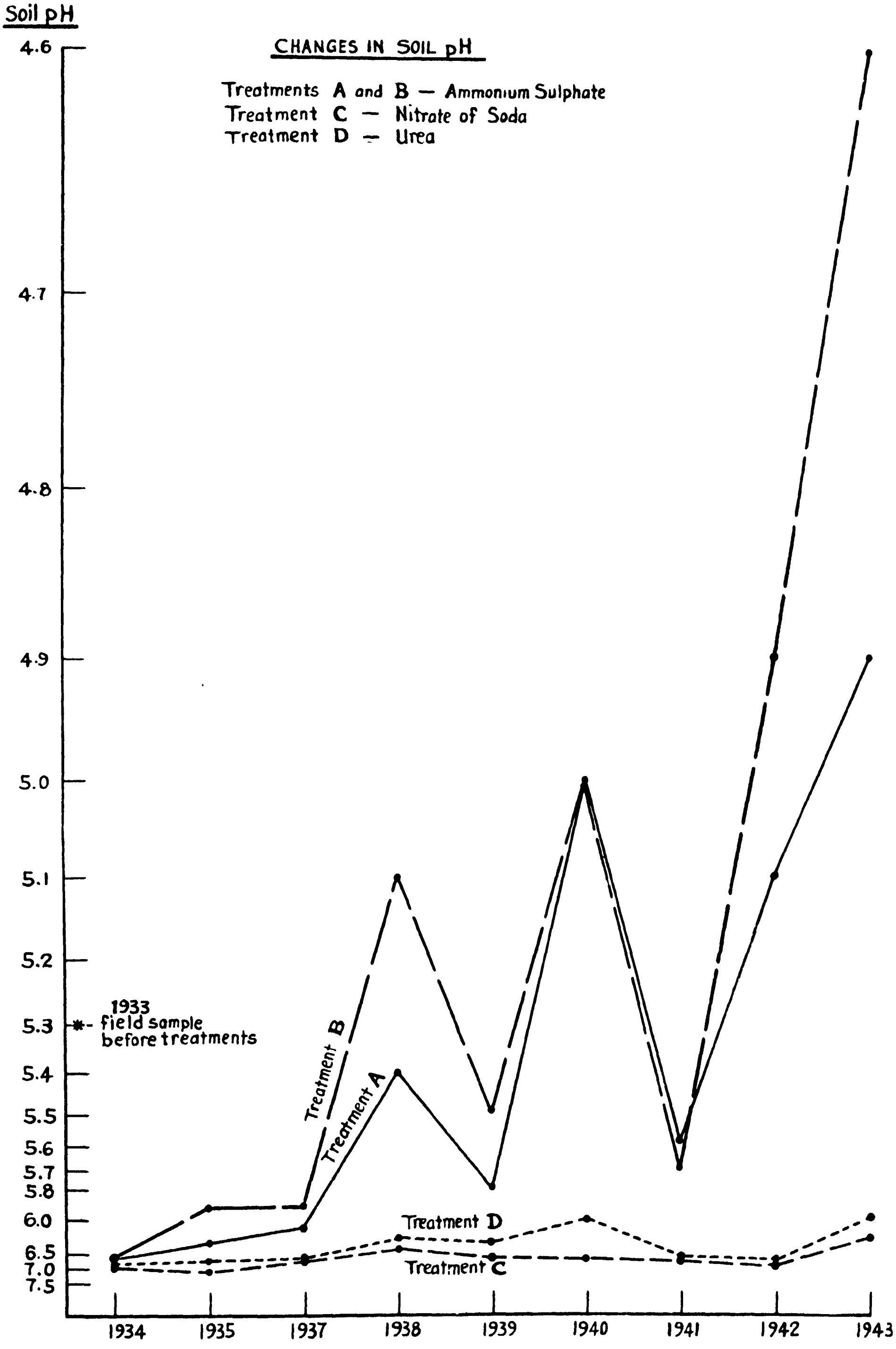
Soil pH
CHANGES IN SOIL pH
Treatments A and B — Ammonium Sulphate
Treatment C — Nitrate of Soda
Treatment D — Urea
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
6.0
6.5
7.0
7.5
1933 field sample before treatments
Treatment B
Treatment A
Treatment D
Treatment C
1934
1935
1937
1938
1939
1940
1941
1942
1943

Fig. 2.

# Weed-spray Studies*

By R. J. Borden

The accompanying series of photographs, when studied with their respective legends, tells a story that needs only a little further elucidation to bring out their chief points of interest.

Most plantation men will agree that the weed *Eleusine indica*, commonly known as "wire-grass" and also as "goose grass," is one of the most persistent and difficult weeds to control in irrigated cane lands. Thus whatever we can learn regarding its destruction and its tolerance to the ordinary field-control, weed-spray practices, is worth-while information.

*Figs. 1, 2, 3:* This group of photographs should be studied together as their only point of difference is that which has resulted from the different dilutions of "Conc. 40" which were sprayed on this wire-grass when it was eight weeks old. In each figure the upper rows show the plants, which had developed under four different environmental conditions, at the time they were first sprayed. The spraying was thorough and all foliage above ground was completely wetted, and the results of the spraying are seen in the center rows. The lower rows show the effects at one month after the initial spraying; in the case of the two weaker dilutions, the original applications had been repeated after one week because they had not caused a satisfactory kill.

Fig. 1 shows that as early as one week after spraying, this tough weed was severely checked by the 1-to-20 dilution, and at one month all of the plants were completely dead. Fig. 2 shows that some kill, chiefly of the leaf blades, had occurred after one week where the 1-to-80 dilution was used, but these plants still had lots of green color left in them. Even the second spraying did not kill these plants which were growing in full sunlight, but a very complete kill of those growing in the shade of cane rows had occurred within the next few weeks. The effect from the initial 1-to-160 dilution after the first week, shown in Fig. 3, was little more than a "burning" of some of the leaves, and a definite "greening up" was taking place when this treatment was repeated. This second spraying with "Conc. 40" at 1-to-160 dilution was again ineffective on weeds which were grown in direct sunlight, but for those grown in the shade, even this very weak dilution soon effected a complete kill.

*Figs. 4, 5, 6:* This group of photographs shows the effects from the three dilutions of "Conc. 40" on wire-grass plants which were eight, six, four, and two weeks old when sprayed. All of these plants were similarly grown in full sunlight with ample soil moisture. Except where the 1-to-20 dilutions were used, the applications with the two weaker dilutions were repeated after one week as their initial kill was not complete.

Fig. 4 shows that all plants were ultimately killed by the initial application of "Conc. 40" diluted 1 to 20. In Fig. 5 we note a kill from the 1-to-80 dilutions that was proportionately greater on the younger weeds. But of special interest is the evidence of individual plant tolerance to this dilution, for although each plant had been completely wetted by the spray, their reaction was different, *e.g.*, in flat No. 17, five four-week-old plants were killed but seven plants were only slightly checked, and in flat No. 20, two of the twelve two-week-old plants were able to survive their two sprayings with this 1-to-80 dilution. Finally Fig. 6 shows that when used at a 1-to-160 dilution, "Conc. 40" failed to kill any of the eight- and six-week-old plants, and killed only 25 per cent of those which were younger.

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* Project A 105—No. 83.2, in cooperation with the Chemistry Department who prepared and applied the herbicides used in this study.

*Fig. 7:* This photograph shows the differential effects from several dilutions of "Conc. 40" and from two other herbicides upon the germination and growth of a few common weed seeds. *Flat No. 2*—When "Conc. 40" diluted 1 to 20 was sprayed on seeds of Spanish needle, amaranth, or purslane, which lay on the surface of the soil, their subsequent germination was nil. And although a few of the wire-grass seeds germinated, and a fair germination of foxtail occurred, their subsequent growth was very weak and sickly. *Flats Nos. 3 and 4*—The weaker dilutions of "Conc. 40" had proportionately less detrimental effects on seed germination and early growth. *Flat No. 5*—The soil-sterilizing effect of the activated sodium chlorate spray prevented a satisfactory growth from the few wire-grass and foxtail seeds which germinated, and stopped the germination of the other weed seeds. *Flat No. 6*—Neither the wire-grass nor the Spanish needle seeds were injured by the Diesel oil spray, although the germination of amaranth and purslane was completely stopped, and only a few foxtail plants appeared above ground.

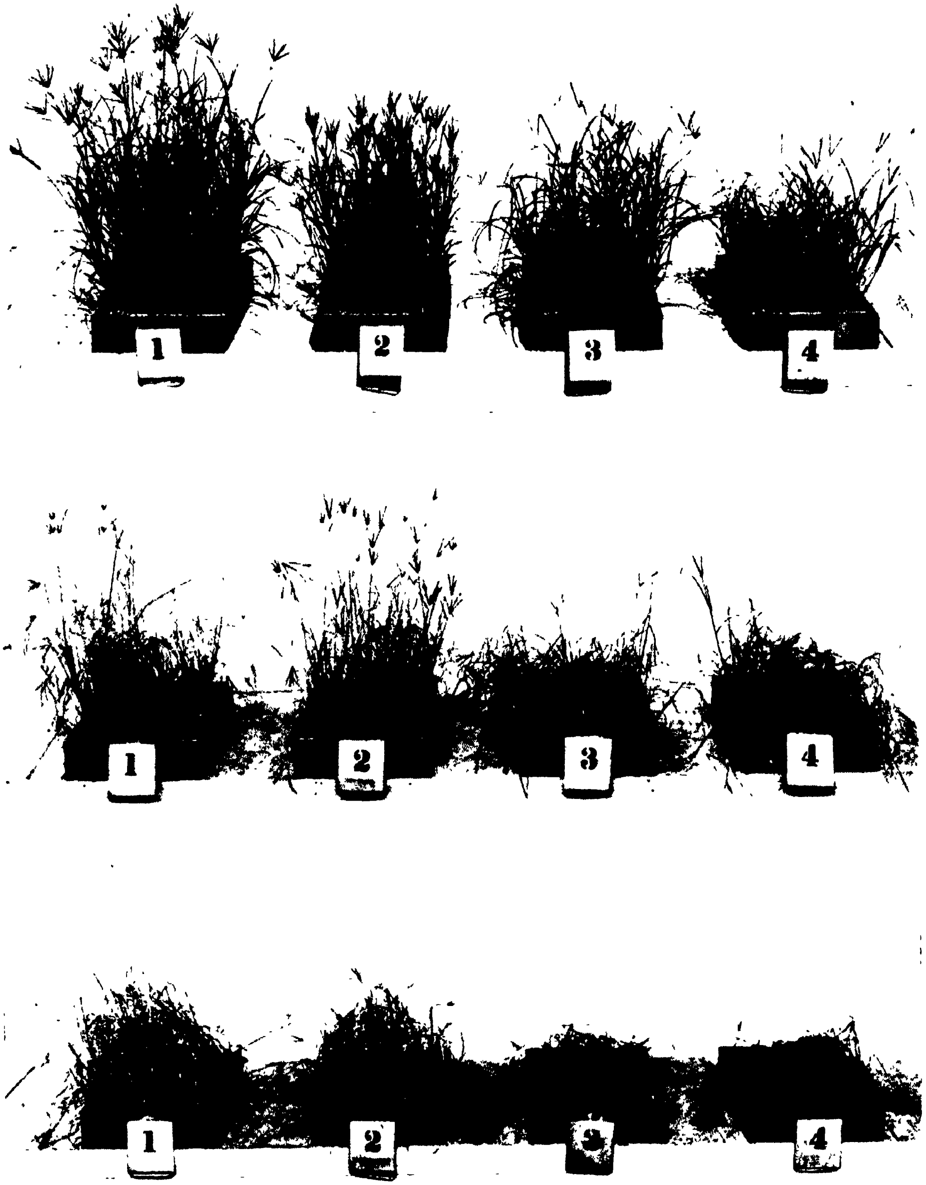


Fig. 1. Wire grass (*Eleusine indica*) 8 weeks old.
Upper row: Before spraying with "Conc.40" *at 1-to-20 dilution.*
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.
No. 1—Grown in full sunlight with ample soil moisture.
No. 2—Grown in full sunlight with inadequate soil moisture.
No. 3—Grown in shade of cane rows with ample soil moisture.
No. 4—Grown in shade of cane rows with inadequate soil moisture.

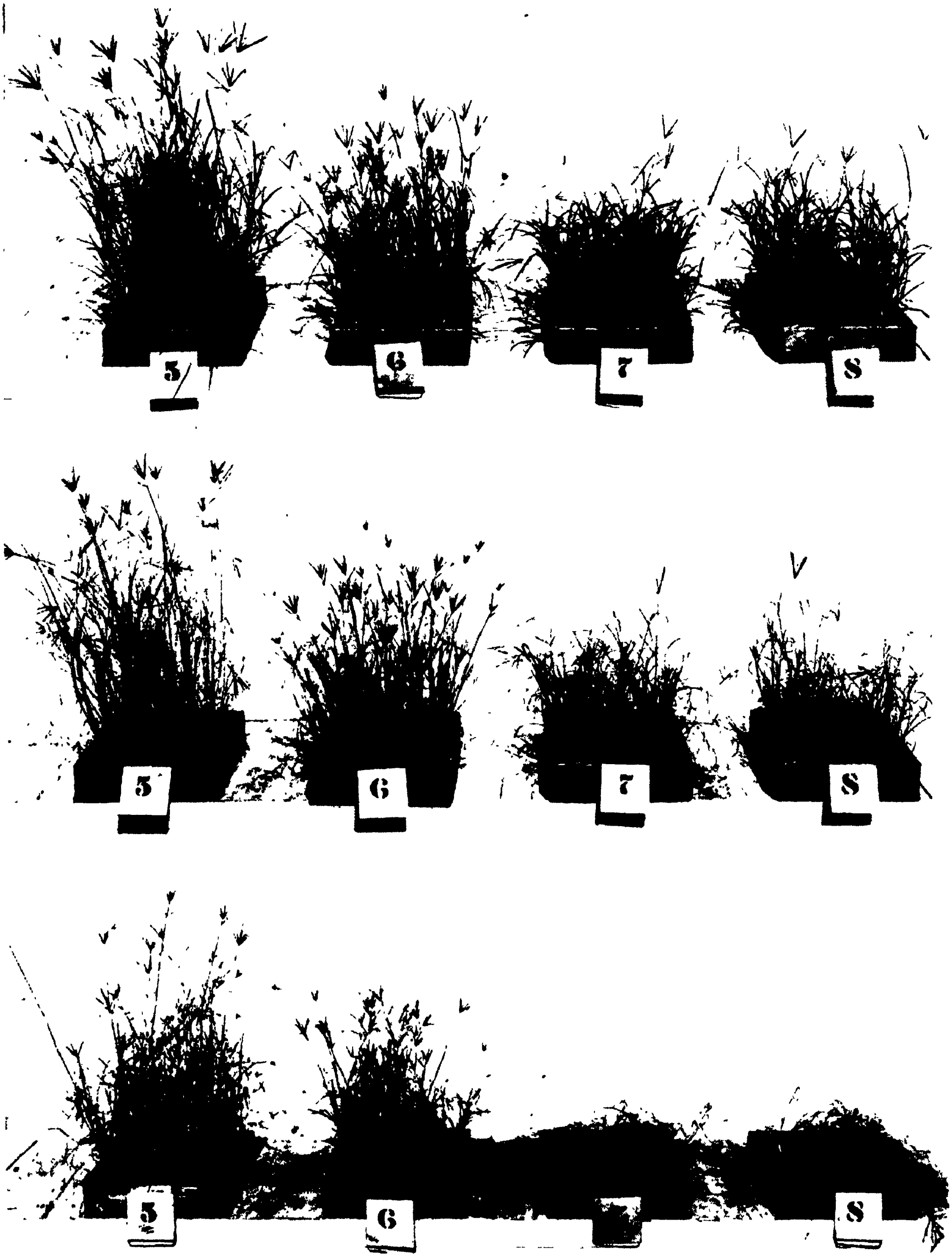


Fig. 2. Wire grass (*Eleusine indica*) 8 weeks old.
Upper row: Before spraying with "Conc.40" *at 1-to-80 dilution.*
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.
No. 5—Grown in full sunlight with ample soil moisture.
No. 6—Grown in full sunlight with inadequate soil moisture.
No. 7—Grown in shade of cane rows with ample soil moisture.
No. 8—Grown in shade of cane rows with inadequate soil moisture.

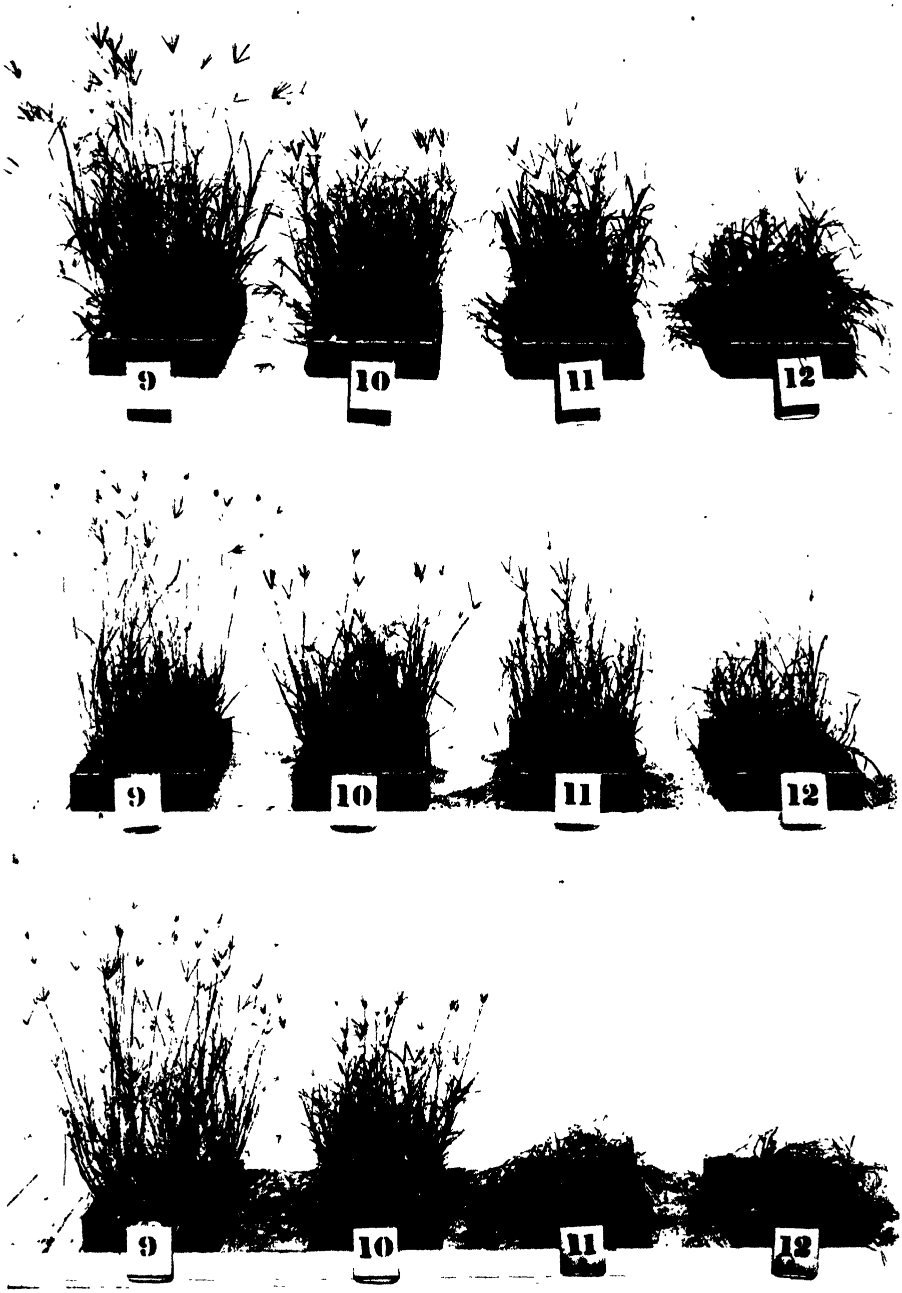


Fig. 3. Wire grass (*Eleusine indica*) 8 weeks old.
Upper row: Before spraying with "Conc.40" *at 1-to-160 dilution.*
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.
No. 9—Grown in full sunlight with ample soil moisture.
No. 10—Grown in full sunlight with inadequate soil moisture.
No. 11—Grown in shade of cane rows with ample soil moisture.
No. 12—Grown in shade of cane rows with inadequate soil moistur

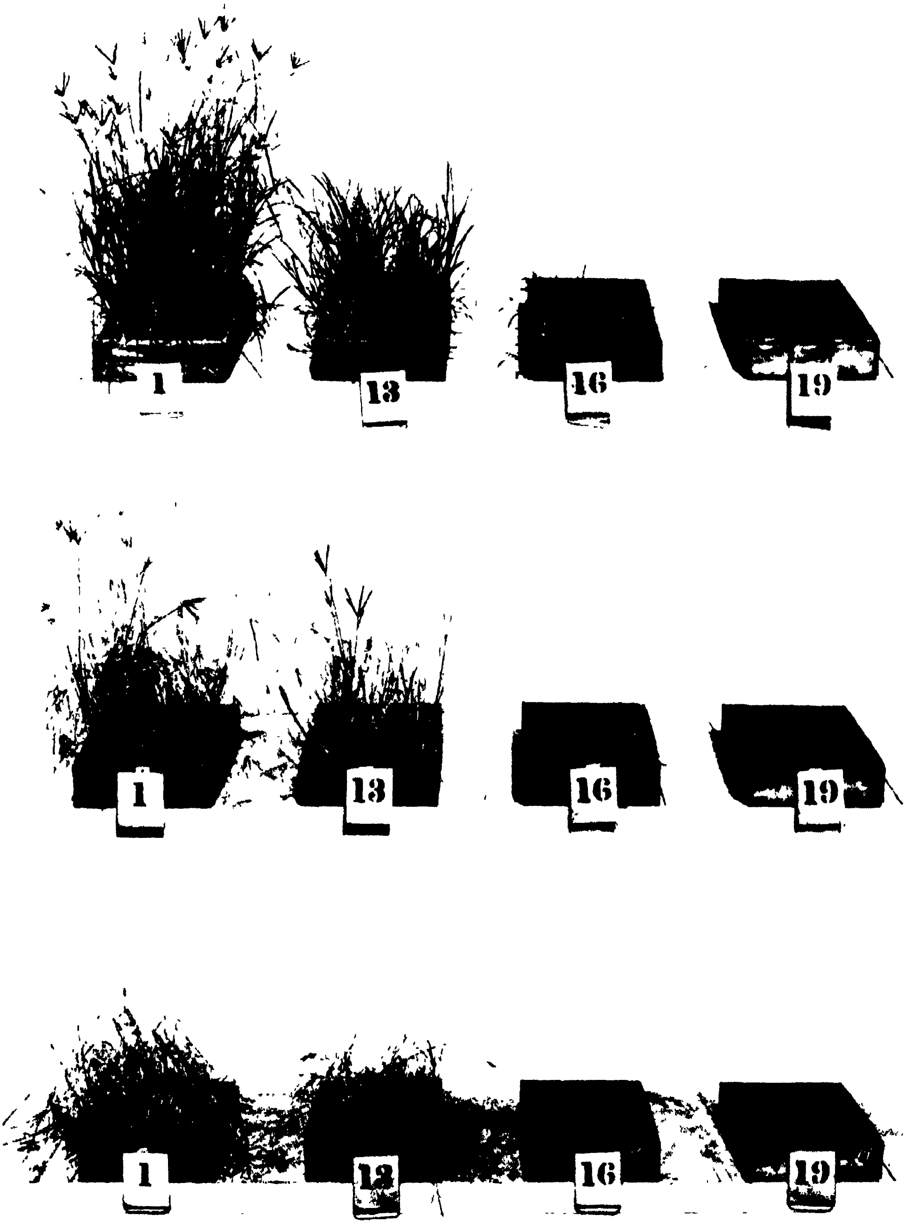


Fig. 4. Wire grass sprayed with "Conc.40" *at 1-to-20 dilution.*
(Grown in full sunlight with ample soil moisture.)
Nos. 1, 13, 16, and 19 were 8, 6, 4, and 2 weeks old respectively when sprayed.
Upper row: Before spraying.
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.

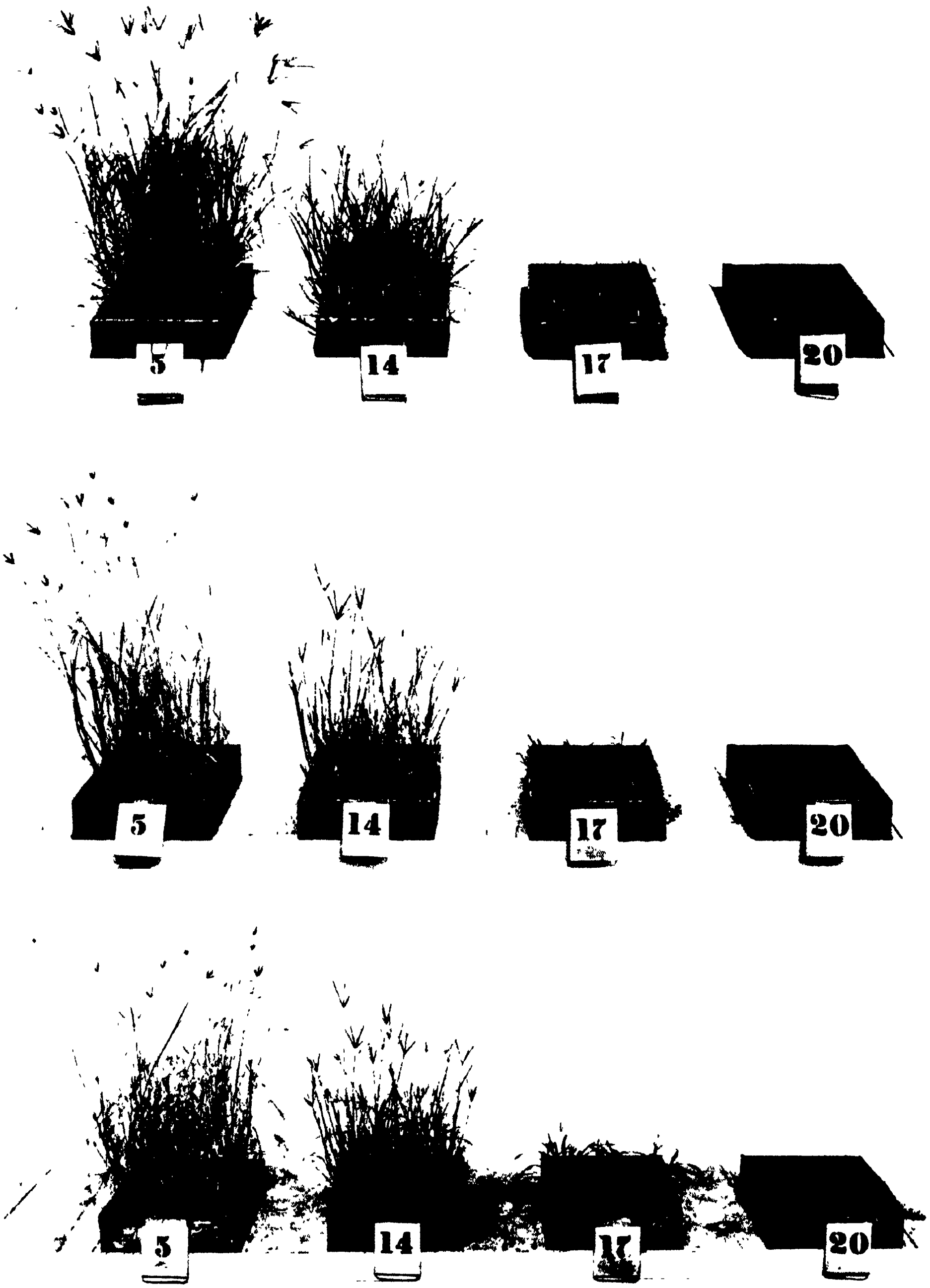


Fig. 5. Wire grass sprayed with "Conc.40" *at 1-to-80 dilution.*
(Grown in full sunlight with ample soil moisture.)
Nos. 5, 14, 17, and 20 were 8, 6, 4, and 2 weeks old respectively when sprayed.
Upper row: Before spraying.
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.

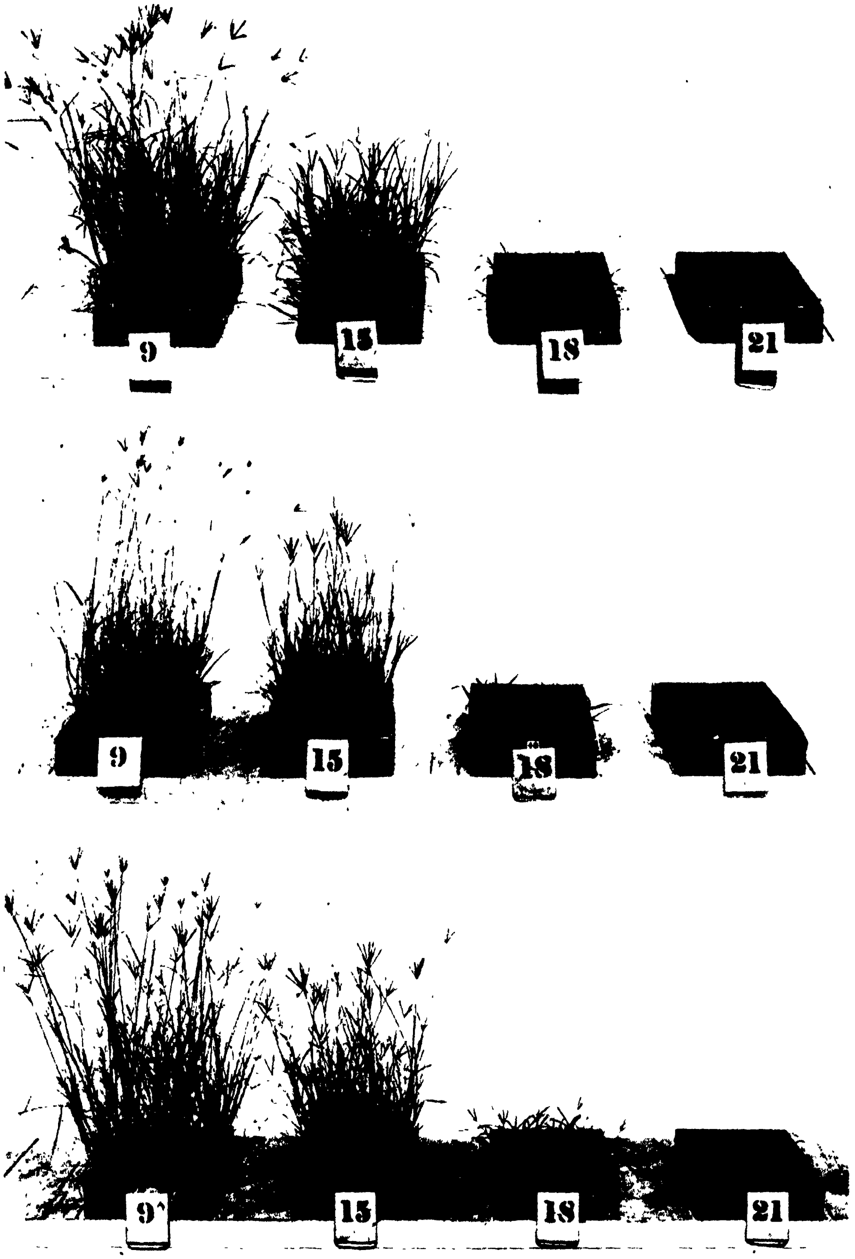


Fig. 6. Wire grass sprayed with "Conc.40" *at 1-to-160 dilution.*
(Grown in full sunlight with ample soil moisture.)
Nos. 9, 15, 18, and 21 were 8, 6, 4, and 2 weeks old respectively when sprayed.
Upper row: Before spraying.
Center row: At 1 week after spraying.
Lower row: At 1 month after spraying.

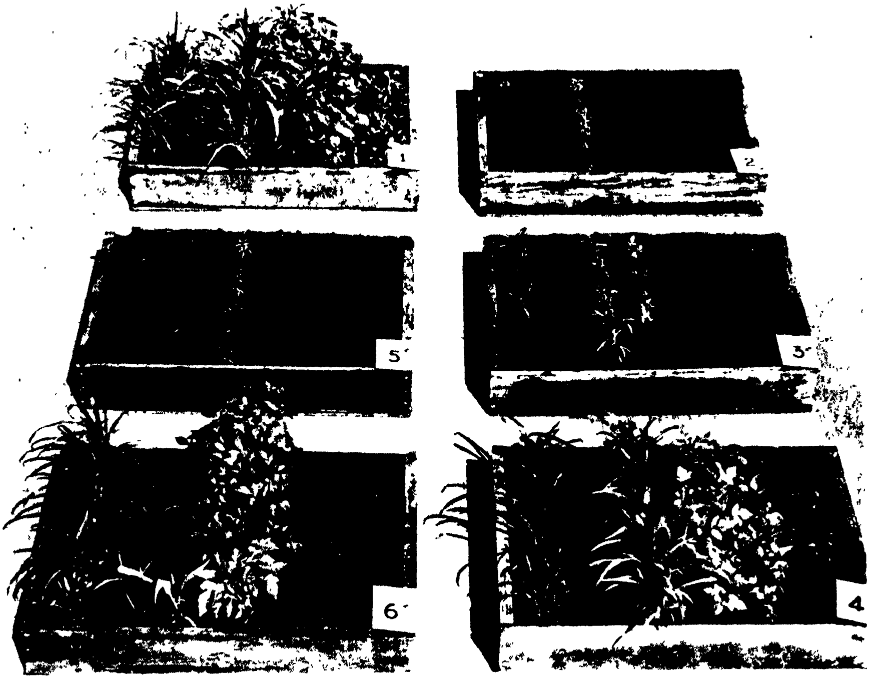


Fig. 7. Effects of Various Herbicides on Weed Seeds.

In each flat, seeds of wire grass, foxtail, Spanish needle, amaranth, and purslane were dropped in rows (left to right) ¼" deep. Both seeds and soil surface were then sprayed with the following herbicides:

1—Tap water (Control).
2—"Conc.40" diluted 1 to 20.
3—"Conc.40" diluted 1 to 80.
4—"Conc.40" diluted 1 to 160.
5—Activated sodium chlorate.
6—Diesel oil emulsion.

After spraying, the seeds were covered with soil, irrigated, and grown for 1 month before photographing.

# The Synthesis of Sucrose in the Sugar Cane Plant—IV

## Concerning the Mechanism of Sucrose Synthesis in the Sugar Cane Plant

By Constance E. Hartt

### *1. Phosphorylation, a part of the mechanism of interconversion and synthesis:*

Phosphorylation, which means the formation of an organic compound with phosphate, is essential for the formation of starch from glucose, according to the work of Hanes (*29*), for the formation of glycogen from glucose, as proved by Cori (10, 11), as well as for other steps in intermediate carbohydrate metabolism. The steps in phosphorylation as determined in higher plants (peas, potatoes) by Hanes and in yeast and animals by Cori and others, may be outlined briefly in the following scheme, in which the enzymes which catalyze the reactions are placed in parentheses:

Starch or glycogen + inorganic phosphate
↓ ↑ (phosphorylase)
Glucose—1-phosphate
↓ ↑ (phosphoglucomutase)
Glucose + adenosine triphosphate ——(hexokinase)——→ Glucose—6—phosphate→Phosphogluconic acid and further steps in aerobic respiration
↓ ↑ (phosphohexoisomerase)
Fructose-6 phosphate
↓ ↑ (phosphorylase)
Fructose 1:6 diphosphate
↓ ↑ (zymohexase)
2 Triose phosphate
↓ (Triose phosphate dehydrogenase)
Further steps in fermentation

The absence of sucrose from this scheme is a glaring omission. Russian workers (47, 49) have presented evidence that phosphorylation is essential for the synthesis of sucrose. A similar conclusion was reached by Hassid (20A and 36).

In the sugar cane plant the following evidence, which was presented in detail in Parts I–III of this paper, indicates that phosphorylation is a part of the mechanism of the interconversion of glucose and fructose and of the formation of sucrose:

*a.* In the blades and roots of plants grown without phosphate, interconversion and synthesis did not take place as well as in plants grown with phosphate.

*b.* The addition of phosphate along with glucose aided the formation of sucrose by detached blades. This aid, however, appears to be an example of the proverb, "To him that hath shall be given," for in Part II of this paper it was shown that the addition of inorganic phosphate increased synthesis in blades of plants grown with phosphate but not in blades of plants grown without phosphate. This may be explained in two ways: (1) Perhaps the addition of inorganic phosphate to the blades of plants grown with phosphate checked the conversion of organic phosphate to inorganic phosphate and thus favored synthesis. (2) Perhaps the plants grown without phosphate had lost the mechanism for utilizing phosphate in synthesis.

*c.* The addition of bone phosphatase along with glucose decreased interconversion and synthesis. Since phosphatase releases inorganic phosphate from organic phosphate, this would indicate that phosphate must be in organic combination for interconversion and synthesis to take place. Bone phosphatase is known from the work of Liebknecht (52) to split off phosphate from adenosine triphosphate, which is the compound which donates phosphate to glucose, according to the scheme already presented. Bone phosphatase also hydrolyzes fructose diphosphate, according to Macleod and Robison (56).

*d.* Inhibiting the action of hexokinase, the enzyme which catalyzes the transfer of phosphate from adenosine triphosphate to glucose, resulted in the inhibition of interconversion and synthesis. It is extremely interesting that the information in the literature regarding the inhibition of hexokinase is entirely in agreement with the findings reported in Part III of this paper regarding the inhibition of interconversion and synthesis. Hexokinase is unaffected by cyanide or phloridzin and is inhibited by M/50 sodium fluoride, according to Case (8). Iri (40), however, reported that 0.01 M fluoride had no effect upon hexokinase. We found that fluoride (380 p.p.m. = 0.02 M = M/50) decreased synthesis considerably, whereas 0.01 M (= 190 p.p.m.) had much less effect. Iri also reported almost complete inhibition of hexokinase by 0.005 M iodoacetic acid, but incomplete inhibition with 0.002 M. These concentrations are between those used in this investigation, but show the same trend. Therefore the results of the effects of inhibitors upon interconversion and synthesis suggest that hexokinase, and hence phosphorylation, plays a part in both processes.

*e.* The ability of blades to carry on interconversion and synthesis fluctuated with the time of day at which the blades were detached from the plant, and the rhythm of fluctuation was the same as that of the movement of phosphate reported by Biddulph (4).

For the above reasons we believe that in the sugar cane plant glucose must react with phosphate before sucrose is formed. Referring again to the scheme of carbohydrate metabolism already presented, we note that the phosphorylation of glucose results in the formation of glucose–6–phosphate, *i.e.*, the phosphate is attached to carbon atom number 6. Glucose–6–phosphate is highly reactive and may follow one of at least three paths. It may form glucose–1–phosphate, phosphogluconic acid, or fructose–6–phosphate. Or it may lose its phosphate, which is not shown in the scheme. Which of these paths does the glucose–6–phosphate take on its way to forming sucrose?

The possibility that the path of sucrose formation is via glucose–1–phosphate, which is known to lead to the formation of starch and glycogen, cannot be overlooked because of the recent work of Doudoroff, Kaplan and Hassid (20a). Using a bacterial preparation, these workers obtained sucrose from glucose–1–phosphate and fructose. The formation of sucrose by the bacterial preparation was not affected by iodoacetic acid or fluoride and did not take place with glucose or fructose alone or together. But in the sugar cane plant sucrose is readily formed from either glucose or fructose, and this formation is inhibited by either iodoacetic acid or fluoride. Furthermore, the bacteria used by Doudoroff and co-workers were dried and ground, but in the sugar cane plant grinding absolutely prevents the formation of sucrose, as shown in Part I of this report. No tests have yet been conducted with sugar cane, in which the formation of glucose-1-phosphate from glucose-6-phosphate is inhibited, or in which glucose-1-phosphate is supplied to detached blades, for which reason we cannot say that the sugar cane plant does or does not make sucrose from glucose-1-phosphate. But if this were the only pathway for the formation of sucrose in the sugar cane plant, how could inhibiting the formation of fructose diphosphate inhibit the formation of sucrose, and how could inhibiting the breakdown of fructose diphosphate increase the formation of sucrose?

The possibility that the path of sucrose formation might be via phosphogluconic acid was examined experimentally. Engelhardt (25) studied the changes of phosphogluconate in yeast maceration juice, and reported that non-phosphorylated gluconic acid behaves in untreated juice similarly to phosphogluconate. A test was therefore conducted using gluconic acid with and without phosphate, supplied to detached blades of the sugar cane plant, and absolutely no sugar was formed.

There remains the possibility that the path of sucrose formation from glucose is via fructose-6-phosphate. This possibility is attractive because the configuration of the sucrose molecule resembles that of both glucose and fructose, because sucrose upon hydrolysis yields both glucose and fructose, and because sucrose is formed in detached blades equally well from either glucose or fructose. Furthermore, the processes of interconversion of glucose and fructose and the formation of sucrose are intimately related, as they are similarly affected by many factors. Many factors have been studied which inhibit the interconversion of glucose and fructose, *e.g.*, lack of aeration, low temperature, arsenite, selenite, fluoride and others. Without exception, whenever the interconversion of glucose and fructose is inhibited, the formation of sucrose is also inhibited. In the experiment with etiolated plants, interconversion took place readily but synthesis was less than usual. In the experiments with brilliant alizarine blue and rosinduline GG, synthesis was affected much more severely than interconversion. Therefore it is possible to inhibit synthesis without inhibiting interconversion. But in these studies no factor has yet been found to inhibit interconversion without inhibiting synthesis. For this reason it seems clear that interconversion takes place either before synthesis or at the same time, and that the two processes are closely related.

Referring again to the scheme of carbohydrate metabolism, one may next inquire how far down the path via fructose-6-phosphate one must proceed before reaching the stepping stone necessary for the formation of sucrose.

To answer this question, let us first turn to the studies with iodoacetate. Weak iodoacetate, in a concentration known to inhibit triose phosphate dehydrogenase, had no effect upon interconversion or synthesis, for which reason "further steps in fermentation" need not be considered as the pathway towards sucrose formation. Iodine, silver nitrate, and copper sulphate, in concentrations known to inhibit zymohexase, increased the synthesis of sucrose a little. But brilliant alizarine blue and rosinduline GG, which inhibit the formation of fructose diphosphate from fructose-6-phosphate, inhibited the synthesis of sucrose.

Because inhibiting the formation of fructose diphosphate resulted in the inhibition of synthesis, whereas inhibiting the breakdown of fructose diphosphate resulted in increasing synthesis, fructose diphosphate is suggested as a necessary stepping stone in the formation of sucrose from glucose or fructose.

2. *Aeration, a part of the mechanism of interconversion and synthesis:*

Experiments reported in Part I of this paper demonstrated that aeration increases the absorption of glucose by detached blades or roots and is absolutely essential for the conversion of glucose to fructose and for the synthesis of sucrose. The exact rôle of aeration in interconversion and synthesis is not known, but may include (*a*) respiration, (*b*) phosphorylation, (*c*) aerobic synthesis, or (*d*) colloidal structure. These four factors will now be discussed.

(*a*) *Respiration:* Synthesis requires the expenditure of energy. Is this energy obtained by aerobic respiration? Although the exact chemical changes which take place in aerobic respiration in plants have not yet been definitely agreed upon, there is considerable evidence that at least two types of respiratory systems function, the cyanide-sensitive and the cyanide-stable. Results presented in Part III of this paper demonstrated clearly that neither interconversion nor synthesis was inhibited by cyanide. Furthermore, this finding was corroborated by tests with pyrophosphate, azide, and 8-hydroxyquinoline, which are among the most important inhibitors of iron-catalyzed and copper-catalyzed reactions. Apparently the oxidases, peroxidases, catalase, and other enzymes containing iron or copper are not involved in interconversion or synthesis, either directly or indirectly. D'yachkov (*22*), however, infiltrated leaves of cabbage, cyclamen and beets with peroxidase and found that it aided synthesis. This conclusion with sugar cane removes from our attention the greater part of aerobic respiration, since the cyanide-sensitive portion of respiration is greater than the cyanide-stable portion of respiration, and focuses our attention upon the cyanide-stable respiration, which is mediated by flavoprotein. A possible rôle of flavoprotein in synthesis is indeed suggested by the results presented in Part II of this paper, as riboflavin significantly increased synthesis in detached roots. However, this is not the whole story, as riboflavin had no effect upon interconversion, whereas aeration is as essential for interconversion as it is for synthesis..

(*b*) *Phosphorylation:* Not only is phosphorylation a part of the mechanism of interconversion and synthesis, as already discussed under that heading, but it is also a source of chemical energy used in cellular syntheses, according to Lipmann (53). Lipmann stated that there are several organic compounds of phosphate which contain energy-rich phosphate bonds. One of these compounds is adenosine triphosphate. As adenosine triphosphate donates phosphate to glucose, forming glucose–6–phosphate, considerable energy is released because the potential energy of adenosine triphosphate is about 10,000 calories while that of glucose–6–phosphate is about 3,000 calories. The energy thus released is used in organic syntheses, according to Lipmann. Since in this process, adenosine triphosphate loses its energy-rich phosphate bond, in order for the process to continue there must be a way in which more energy-rich phosphate bonds can be formed. Lipmann reviewed three ways whereby energy-rich phosphate bonds are formed: anaerobically by fermentation, and aerobically by alpha keto acid oxidation and dicarboxylic acid oxidation. The aerobic methods are more efficient than the anaerobic, as they yield more energy-rich phosphate bonds per molecule of glucose.

Since aeration is essential for interconversion and synthesis, whereas fermentation can be inhibited without interfering with interconversion and synthesis, the generation of energy-rich phosphate bonds in sugar cane is probably an aerobic process.

The method of alpha keto acid oxidation includes the dehydrogenation of pyruvate, which has been demonstrated in *Bacterium Delbrueckii,* brain, and kidney, and the oxidation of ketoglutarate, which has been demonstrated in kidney. In sugar cane, pyruvate has been used in several tests, and there was no evidence that it aided synthesis. Ketoglutarate has not yet been used.

The method of dicarboxylic acid oxidation includes the dehydrogenation of succinic, fumaric, and malic acids, which have been demonstrated in kidney. Szent-Györgyi's (*79*) theory of the rôle of the $C_4$ dicarboxylic acids in the respiration of animals is well known. In plants, Szent-Gyorgyi has stressed the importance of dihydroxymaleic acid, which is an oxide of succinic acid. Pucher and Vickery (*71*) have established the fact that succinic acid is widespread in plants, although it is only a minor constituent of leaves. Damodarau (15) reported the occurrence of succinic dehydrogenase in leguminous seedlings, and demonstrated the existence of the complete succinoxidase system in plants.

Although it appears well established that succinic acid and its dehydrogenase occur in plants and may take part in plant respiration, there is evidence against the theory that the dehydrogenation of succinate is essential for the phosphorylation of glucose in the sugar cane plant. Pyrophosphate, malonate, and sodium diethyldithiocarbamate are strong and specific inhibitors of succinic dehydrogenase, but did not inhibit synthesis.

Fumaric acid is converted to malic acid by the enzyme fumarase, for which no specific inhibitor is known to the writer. Fumaric acid increased synthesis a little, as reported in Part III of this paper.

Malic acid is a well-known constituent of plants. Vickery (82) has shown that malic acid increases in rhubarb leaves cultured in glucose in the dark and suggested that the metabolism of malic acid is connected with the metabolism of carbohydrate. In the leaves of Sudan grass, Wood (84) reported a correlation between respiration rate, sucrose, and malic acid. A comparison of the effects of inhibitors upon malic dehydrogenase as recorded in the literature with the effects of inhibitors upon the synthesis of sucrose reported in Part III of this paper is presented in Table I. The agreement is not perfect. Arsenite in as low a concentration as 5 parts per million decreases synthesis a little; but this may be due to an effect upon some other enzyme, since arsenite is a bad poison. The fact that fluoride, which depressed synthesis, has no effect upon malic dehydrogenase, need not throw that enzyme out of con-

TABLE I

THE EFFECTS OF INHIBITORS UPON MALIC DEHYDROGENASE COMPARED WITH THEIR EFFECTS UPON SUCROSE SYNTHESIS IN SUGAR CANE

| Inhibitor | Effect upon malic dehydrogenase | Reference | Effect upon sucrose synthesis |
|---|---|---|---|
| Cyanide | Accelerated a little | Leloir & Dixon (50) | No effect (sometimes accelerated) |
| Arsenite | Inhibited (.15M) | Das (16) | |
| | Accelerated (.03M) | Green (27) | Inhibited |
| Iodoacetate (.01M) | Inhibited | Elvehjem (23) | Inhibited |
| Fluoride | No effect | Das (16) | Inhibited |
| Pyrophosphate | Accelerated | Green (27) | Accelerated |
| Malonate | No effect | Leloir & Dixon (50) | Little effect |
| Urethane | Inhibited a little | Green (27) | No effect |

sideration, for fluoride is known to inhibit hexokinase, as already mentioned. Malic dehydrogenase fits the picture much better than succinic dehydrogenase, but it is also possible that some other dehydrogenase is involved. Hibbert (38) reported a new oxidation-reduction system widespread in plants, consisting of methyl guaiacyl diketone and alpha hydroxypropiovanillone. Although much is known concerning the distribution of organic acids in plants, a considerable portion of the organic acid fraction is still "unknown acids." The possibility remains that one or more of these unknown acids with their dehydrogenases may be of importance in that part of aerobic respiration leading to the production of energy-rich phosphate bonds.

The theory that malic acid with its dehydrogenase may aid the formation of sucrose was tested by supplying malic acid with and without glucose to detached blades. The results of the determinations of moisture and sugars are recorded in Table II, and the gains in sugars and synthetic efficiencies in Table III. Malic acid alone decreased the loss in total sugars and sucrose and may have substituted for sugar as a source of energy. Malic acid alone made no sucrose, but when given with glucose increased the gains in total sugars and sucrose and increased the synthetic efficiency. These results are in accord with the theory that malic acid aids in the synthesis of sucrose.

TABLE II

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT MALIC ACID (5 GMS/L) ADJUSTED TO pH 5 WITH NaOH

| Series | Moisture | Reducing sugars | Sucrose | Total sugars |
|---|---|---|---|---|
| Initial control ..... | 70.67 ± 0.057 | 0.523 | 2.281 | 2.941 ± 0.008 |
| Water ............ | 71.10 ± 0.019 | 0.496 ± 0.002 | 1.692 ± 0.000 | 2.277 ± 0.001 |
| Malic acid ......... | 71.23 ± 0.011 | 0.711 ± 0.002 | 1.933 ± 0.007 | 2.747 ± 0.009 |
| Glucose ............ | 69.16 ± 0.052 | 1.149 ± 0.011 | 3.413 ± 0.016 | 4.742 ± 0.002 |
| Glucose + malic acid | 70.12 ± 0.019 | 1.094 ± 0.008 | 3.827 ± 0.023 | 5.123 ± 0.032 |

TABLE III

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT MALIC ACID (5 GMS/L) ADJUSTED TO pH 5 WITH NaOH, CALCULATED FROM TABLE II

| Series | Gain in total sugars | Gain in sucrose | Synthetic efficiency |
|---|---|---|---|
| Water ........................ | - 0.664 | 0.589 | |
| Malic acid .................... | - 0.194 | -- 0.348 | |
| Glucose ....................... | 1.801 | 1.132 | 62.85 |
| Glucose + malic acid .......... | 2.182 | 1.546 | 70.85 |

Therefore aeration is essential for interconversion and synthesis because the aerobic dehydrtogenation of malic acid (or some related acid) forms the energy-rich phosphate bonds, and the energy-rich phosphate bond of adenosine triphosphate is transferred to glucose by hexokinase, forming glucose-6-phosphate, which constitutes the first step in both interconversion and synthesis.

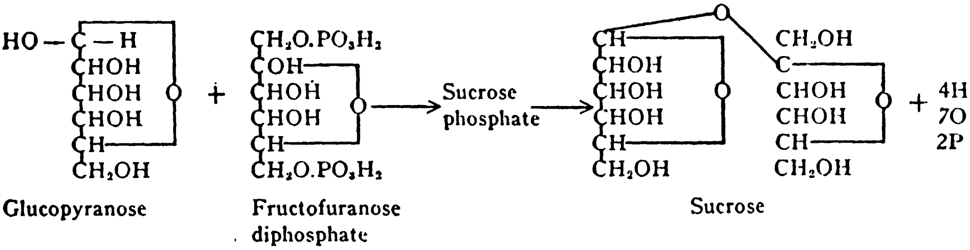
(*c*) *Aerobic synthesis:* Since the first step in both interconversion and synthesis requires aeration, it cannot yet be proved from our results that the final step in synthesis requires aeration. If we could supply blades with fructose diphosphate with and without aeration, we might determine whether aeration is required for the formation of sucrose from fructose diphosphate. Studies of this nature are now under way. Synthetic reactions in general require energy, and this energy comes from the phosphorylation of glucose, according to Lipmann.

(*d*) *Colloidal structure:* D'yachkov (*22*) is of the opinion that the energy of respiration is used for the maintenance of heterogeneity of living plasma required for synthesis. This theory was not tested in the present investigation.

Aeration, therefore, may aid interconversion and synthesis in more than one way: by facilitating the cyanide-stable respiration mediated by flavoprotein; and by facilitating the aerobic dehydrogenation of malic acid (also cyanide-stable) which is essential for the phosphorylation of glucose.

### *3. The conversion of fructose diphosphate to sucrose:*

The final step to be discussed is the conversion of fructose diphosphate to sucrose. Consideration of the molecule of sucrose shows that half of the sucrose molecule closely resembles fructose diphosphate and the other half closely resembles glucose. If glucose should unite with fructose diphosphate, sucrose or its immediate forerunner might result, according to the following equation. The proposal of sucrose phosphate as the immediate forerunner of sucrose is justified by the fact that sucrose phosphates have been prepared (*63*), and enzymes capable of acting on sucrose phosphates are known to occur in both plants and animals (*20*, *62*).



The above equation shows that the following would be left over: 4H, 7O, 2P. This might be accomplished in at least two ways: by the removal of one molecule of pyrophosphoric acid ($H_4P_2O_7$), or by the simultaneous removal of one molecule of water and two molecules of metaphosphoric acid ($H_2O + 2HPO_3$).

Now it is conceivable that the phosphate might go off in the inorganic form or that it might be taken by an organic phosphate acceptor. If the phosphate goes off in the inorganic form, there should be an increase in inorganic phosphate in cane during ripening. Ayres (*2*) reported that the percentage of phosphate in the stalk decreased from 4 to 8 months and then remained the same until 14 months, but he did not distinguish between organic and inorganic phosphate. If the phosphate goes off in the inorganic form, the process should be aided by a phosphatase and phosphatase should increase the formation of sucrose; but, as shown in Part II of this paper, bone phosphatase decreased synthesis. But a specific phosphatase, differing from bone phosphatase, may be required to split sucrose phosphate. Neuberg (*62*) reported that sucrose phosphoric acid is converted by kidney phosphatase into sucrose and phosphoric acid. Pratesi (*70*) discovered that phosphatase extracted from the leaves of geranium, rose, lily and violet splits calcium sucrose phosphate, the action being best at pH 4.2–6.7.

The possibility that the phosphate is taken by an organic phosphate acceptor will now be considered. Cocarboxylase is known to be the pyrophosphoric acid ester of vitamin $B_1$. The yellow enzyme is a riboflavin-phosphoric acid-protein complex. Both vitamin $B_1$ (= thiamin) and vitamin $B_2$ (= riboflavin) must obtain phosphate from someplace, and either of them might act as the organic phosphate acceptor needed for the formation of sucrose from glucose and fructose diphosphate. Harris (30) reported that vitamin $B_1$ is phosphorylated through the agency of adenosine triphosphate. Horowitz (39) found that in the pea, carboxylase is partially inactivated by its action on pyruvate, that vitamin $B_1$ is released by this inactivation, and that the enzyme can be reactivated by adding pyrophosphate.

Evidence that thiamin and riboflavin aid in the synthesis of sucrose was presented in Part II of this paper. Of considerable interest is the absence of any evidence that these vitamins aid in the interconversion of glucose and fructose, which would only be expected if their function is to remove the phosphate from sucrose phosphate. Etiolated shoots were found to lack something necessary for synthesis but were well able to carry on the interconversion of glucose and fructose, for when supplied with glucose they accumulated fructose, and when supplied with fructose they accumulated glucose, as reported in Part I of this paper. Etiolated shoots are known to contain auxins but to lack certain vitamins, including thiamin and riboflavin. Roots were found to obtain something essential for synthesis from tops; this "something" was found to be air and probably something else. Roots are known to obtain certain vitamins from tops, including thiamin and riboflavin.

For these reasons it is suggested that thiamin or riboflavin may aid in the synthesis of sucrose by removing phosphate from sucrose phosphate, with or without the aid of a specific phosphatase.

This section is headed "The conversion of fructose diphosphate to sucrose." The evidence that this conversion takes place is purely circumstantial, as such a reaction has not yet actually been observed in the test tube. Studies with fructose diphosphate designed to test the theory directly are now in progress.

### *4. Conclusion:*

The mechanism of the synthesis of sucrose in the sugar cane plant includes phosphorylation and aeration. With the aid of hexokinase, some of the glucose absorbed by the blades is phosphorylated by the energy-rich phosphate bond of the adenosine triphosphate already present in the blades. This aerobic process results in the formation of more energy-rich phosphate bonds, perhaps by the dehydrogenation of malic acid, and these bonds are used for the reformation of adenosine triphosphate. Some of the phosphorylated glucose is converted to fructose monophosphate and then to fructose diphosphate. Some of the fructose diphosphate may be broken down anaerobically, but most of it combines with glucose using the energy released by phosphorylation, forming a sucrose phosphate. A phosphate acceptor such as thiamin or riboflavin, with perhaps the aid of a specific phosphatase, accepts the phosphate and thus sucrose is formed.

These reactions, though long in the telling (and in the reading) probably take place practically instantaneously in the plant.

Fructose is just as good a substrate as glucose for the synthesis of sucrose. Following the outline presented for glucose, the phosphorylation of fructose should result in the formation of fructose–6–phosphate. Some of this fructose monophosphate would need to be converted to fructose diphosphate, while some would be changed to glucose monophosphate and then to glucose. The glucose would then combine with the fructose diphosphate, resulting in the formation of sucrose phosphate. Thus the formation of sucrose would take place by the same mechanism whether glucose or fructose is the starting point. The only difference is that both of the reactants have to be made when fructose is supplied, whereas only one reactant has to be made when glucose is supplied.

The formation of sucrose in the plant results not only in a storing of sugar which thus is not all broken down at once, but also in the release of phosphate which can be used again.

## ACKNOWLEDGEMENTS

The writer is deeply indebted to Dr. H. L. Lyon for suggestions and advice in the course of this study, and to Miss Ada Forbes who has been of constant assistance throughout the investigation. Credit is also due to Miss Ingrid Larsen and Miss Catherine Cooke who performed some of the analyses.

## LITERATURE CITED

(1) Allen, R. J. L., 1939. The rôle of phosphorus compounds in the carbohydrate metabolism of the potato. Rept. Food Invest, Board of 1938, London, pp. 196–198.

(2) Ayres, Arthur, 1936. Effect of age upon the absorption of mineral nutrients by sugar cane under field conditions. Jr. Am. Soc. Agron., 28: 871–886.

(3) Barker, S. B., Shorr, E., and Malam, M., 1939. Studies on the Pasteur reaction: effect of iodoacetic acid on the carbohydrate metabolism of isolated mammalian tissues. Jr. Biol. Chem. 129: 33–50.

(4) Biddulph, O., 1941. Diurnal migration of injected radiophosphorus from bean leaves. Am. Jr. Bot., 28: 348–352.

(5) Borei, H., 1939. Influence of fluoride on cytochrome and on cytochrome oxidase. Arkiv Kemi, Mineral. Geol. 13 A: 13 pp.

(6) Boswell, J. G., and Whiting, G. C., 1940. Oxidase systems in the tissues of the higher plants. New Phytol., 39: 241–265.

(7) Burris, R. H., and Wilson, P. W., 1939. Respiratory enzyme systems in symbiotic nitrogen fixation. Cold Spring Harbor Symp. Quant. Biol., 7: 349–361.

(8) Case, E. M., 1929. Glycolysis in muscle and other tissues. Biochem. Jr., 23: 210–218.

(9) Commoner, Barry, 1940. Cyanide inhibition as a means of elucidating the mechanisms of cellular respiration. Biol. Rev., 15: 168–201.

(10) Cori, Carl F., 1939. Enzymatic breakdown and synthesis of carbohydrate. Cold Spring Harbor Symp. Quant. Biol., 7: 260–268.

(11) ——————, 1941. Phosphorylation of glycogen and glucose. Biol. Symp., 5: 131–140.

(12) Cori, Gerty T., and Cori, Carl F., 1940. The kinetics of the enzymatic synthesis of glycogen from glucose–1–phosphate. Jr. Biol. Chem., 135: 733–756.

(13) Crafts, A. S., 1935. Physiological problems connected with the use of sodium chlorate in weed control. Plant Physiol., 10: 699–711.

(14) Dahl, O., 1939. Interference of phosphorylation of starch and glycogen degradation products in muscle extract. Arkiv Kemi, Mineral. Geol., 13 A: 1–17.

(15) Damodarau, M., and Venkatesan, T. R., 1941. Succinoxidase in plants. Proc. Indian Sci. Cong., 28; paper No. 31.

(16) Das, N. B., 1937. Identity of lactic and malic dehydrogenases. Biochem. Jr., 31: 1116–1123.

(17) Deleano, N. T., and Dick, J., 1939. Beiträge zum Studium der Auswanderung der Assimilate aus den Laubblättern mit chloroformierten Blattstielen. Beitr. Biol. Pflanzen, 26: 81–89.

(18) Dixon, Malcolm, 1939. Biological oxidations and reductions. Ann. Rev. Biochem., 8: 1–36.

(19) ——————, and Elliott, K. A. C., 1929. The effect of cyanide on the respiration of animal tissues. Biochem. Jr., 23: 812–830.

(20) Djenab, K., and Neuberg, C., 1917. Saccharophosphatase of yeasts and the fermentation of sucrose phosphoric acid. Biochem. Ztschr., 82: 391–411.

(20a) Doudoroff, M., Kaplan, N., and Hassid, W. Z., 1943. Phosphorolysis and synthesis of sucrose with a bacterial preparation. Jr. Biol. Chem., 148: 67–75.

(21) duBuy, H. G., and Olson, R. A., 1940. The relation between respiration, protoplasmic streaming and auxin transport in the Avena coleoptile, using a polarographic microrespirometer. Am. Jr. Bot., 27: 401–413.

(22) D'yachkov, N. N., 1941. The physiological rôle of peroxidase in plants. Biokhimiya, 6: 440–446.

(23) Elvehjem, C. A., and Wilson, P. W., 1939. Respiratory enzymes. Burgess Publishing Co., Minneapolis, Minn., 236 pp.

(24) Enders, C., and Wieninger, F. M., 1937. The effect of alkaloids on fermentation and multiplication of yeast. Biochem. Ztschr., 293: 22–29.

(25) Engelhardt, W. A., and Barchash, A. P., 1938. The oxydative breakdown of phosphogluconic acid. Biokhimiya, 3: 500.

(26) Gay, N. M., 1941. Chemical weed control. Letter to Dr. F. E. Hance, Project File, Experiment Station, H.S.P.A.

(27) Green, D. E., 1936. The malic dehydrogenase of animal tissues. Biochem. Jr., 30: 2095–2110.

(28) Hance, Francis E., 1938. Chemical weed control. The Hawaiian Planters' Record, 42: 3–37.

(29) Hanes, C. S., 1940. The breakdown and synthesis of starch by an enzyme system from pea seeds. Proc. Roy. Soc. Lond. Ser. B 128: 421–450.

(30) Harris, L. J., 1940. Biochemistry. Nutrition and vitamins. Ann. Repts. on the Progress of Chemistry. The Chemical Society, London, 37: 382–394.

(31) Hartt, Constance E., 1934. Some effects of potassium upon the amounts of protein and amino forms of nitrogen, sugars, and enzyme activity of sugar cane. Plant Physiol., 9: 453–490.

(32) ——————, 1935. The fluctuations of sugars in the leaf blades of the sugar cane plant during the day and the night. The Hawaiian Planters' Record, 39: 298–326.

(33) ——————, 1937. The synthesis of sucrose by excised blades of sugar cane. The Hawaiian Planters' Record, 41: 33–46.

(34) ——————, 1939. Enzyme Laboratory. Rept. Com. in charge of the Experiment Station, H.S.P.A., pp. 113–116.

(35) ——————, 1940. The synthesis of sucrose by excised blades of sugar cane. Time and temperature. The Hawaiian Planters' Record, 44: 89–116.

(36) Hassid, W. Z., 1938. Isolation of a hexosemonophosphate from pea leaves. Plant Physiol., 13: 641–647.

(37) Herbert, D., Gordon, H., Subrahmanyan, V., and Green, D. E., 1940. Zymohexase Biochem. Jr., 34: 1108–1123.

(38) Hibbert, Harold, 1940. The mechanism of plant respiration. Jr. Am. Chem. Soc., 62: 984–985.

(39) Horowitz, N. H., and Heegaard, Erik, 1941. Experiments on the carboxylase of pea roots. Jr. Biol. Chem., 137: 475–483.

(40) Iri, S., 1939. On the mechanism of the action of hexokinase. Jr. Biochem., 30: 217–224.

(41) Irving, Annie A., 1911. The effect of chloroform upon respiration and assimilation. Ann. Bot., 25: 1077–1099.

(42) Kalckar, Herman, 1937. Phosphorylation in kidney tissue. Enzymolog., 2: 47–52.

(43) Keilin, D., and Hartree, E. F., 1936. On some properties of catalase haematin. Proc. Roy. Soc., London, Ser. B 121: 173–191.

(44) ——————, and ——————, 1940. Succinodehydrogenase-cytochrome system of cells. Intracellular respiratory system catalyzing aerobic oxidation of succinic acid. Proc. Roy. Soc., London, Ser. B 129: 277–306.

(45) Kempner, Walter, 1939. The role of oxygen tension in biological oxidations. Cold Spring Harbor Symp. Quant. Biol., 7: 269–289.

(46) King, C. G., 1939. The water-soluble vitamins. Ann. Rev. Biochem., 8: 371–414.

(47) Kryukova, N., 1940. Synthesis and hydrolysis of sucrose in the tissues of higher plants under the conditions of inhibited phosphorylation. Biokhimiya, 5: 574–583.

(48) Kurssanov, A. L., 1936. Reversible Wirkung von Invertase in Pflanzenzellen und die Rolle der Strukturelemente des Protoplasmas. Biokhimiya, 1: 411–424.

(49) ————————, 1940. Reversible action of enzymes in living plant cells. Biochem. Inst. Acad. Sci., U.S.S.R., Moscow, pp. 1–232.

(50) Leloir, L. F., and Dixon, M., 1937. The action of cyanide and pyrophosphate on dehydrogenases. Enzymolog., 2: 81–88.

(51) Leonard, O. A., 1939. Carbohydrate transformations in leaf blades, with special reference to sucrose synthesis. Am. Jr. Bot., 26: 475–484.

(52) Liebknecht, W. L., 1939. Hydrolysis of adenyl pyrophosphate by bone phosphatase. Biochem. Ztschr., 303: 96–100.

(53) Lipmann, Fritz, 1941. Metabolic generation and utilization of phosphate bond energy. Advances in Enzymology, 1: 99–162.

(54) Lisitsyn, D. I., 1941. The effect of phlorizin on the sugar transformation in leaves. Biokhimiya, 6: 482–486.

(55) Macfarlane, Marjorie Giffen, 1939. The phosphorylation of carbohydrate in living cells. Biochem. Jr., 33: 565–578.

(56) Macleod, M., and Robison, R., 1933. The hydrolysis of hexose diphosphoric ester by bone phosphatase. A new fructosemonophosphate. Biochem. Jr., 27: 286–297.

(57) Martland, M., and Robison, R., 1929. The preparation and use of the bone phosphatase. Biochem. Jr., 23: 237–242.

(58) McCready, R. M., and Hassid, W. Z., 1941. Transformation of sugars in excised barley shoots. Plant Physiol., 16: 599–610.

(59) Mendel, Bruno, and Strelitz, F., 1937. Specific action of ferricyanide on aerobic glycolysis of tumour cells. Nature, 140: 771–772.

(60) Meyerhof, O., 1930. The chemistry of muscular contraction. The Lancet, 2: 1415–1422.

(61) Michaelis, Leonor, and Smythe, C. V., 1936. Influence of certain dyestuffs on fermentation and respiration of yeast extract. Jr. Biol. Chem., 113: 717–734.

(62) Neuberg, C., Behrens, M., Dalmer, O., Hatano, J., Rosenfeld, L., and Sabetay, S., 1926. Chemical and biochemical degradations of sucrosephosphoric acid. Z. ver. deut. Zuckerind., pp. 463–493.

(63) — ———, and Pollak, H., 1910. Carbohydrate esters of phosphoric acid. Biochem. Ztschr., 23: 515–517.

(64) Norris, F. W., 1939. Plant biochemistry. Ann. Repts. on Progress of Chemistry, The Chemical Society, London, 36: 362–387.

(65) Nurmia, M., 1935. Transformation of sugars in plants. Ann. Acad. Sci. Fennicae Ser. A. 44, No. 8: 1–105.

(66) Oparin, A., and Kurssanov, A. L., 1931. Über die enzymatische Synthese des Rohrzuckers, Biochem. Ztschr. 239: 1–17.

(67) Oppenheimer, C., and Stern, K. G., 1939. Biological oxidation. Nordemann Publishing Company, New York.

(68) Ostern, P., Baranowski, T., and Terszakowec', J., 1938. The phosphorylation of adenosine by yeast and the role of this process in alcoholic fermentation. Hoppe-Seyler's Z. physiol. Chem., 251: 258–284.

(69) Pillai, R. K., 1938. Action of arsenate in glucolysis. Biochem. Jr., 32: 1961–1973.

(70) Pratesi, P., 1937. The presence of phosphatase in green leaves. I. Ann. chim. applicata, 27: 309–321.

(71) Pucher, George W., and Vickery, Hubert, 1941. Determination of succinic acid in plant tissues. Ind. Eng. Chem. Anal. Ed., 13: 412–415.

(72) Ramasarma, G. B., Datta, N. C., and Doctor, N. S., 1940. Studies on ascorbic acid oxidase. Enzymolog., 8: 108–112.

(73) Rapkine, L., 1938. Sulfhydryl groups and enzymic oxidation-reduction. Biochem. Jr., 32: 1729–1739.

(74) Runnström, J., Borei, H., and Sperber, E., 1939. How does fluoride depress yeast respiration? Arkiv Kemi, Mineral. Geol., 13 A, 29 pp.

(75) Shmuck, A. A., Gusseva, A., and Ilyin, G., 1939. Comparative effects of acenaphthene in plants and of carcinogenic compounds upon animal tissues. Biokhimiya, 4: 470–482.

(76) Smythe, C. V., 1937. An improved method of preparing hexose-monophosphate from yeast extract. Jr. Biol. Chem., 118: 619–625.

(77) Spoehr, H. A., and Milner, Harold W., 1939. Starch dissolution and amylolytic activity in leaves. Proc. Am. Phil. Soc., 81: 37–78.

(78) Szent-Györgyi, Albert V., 1930. The action of arsenite on tissue respiration. Biochem. Jr., 24: 1723–1727.

(79) ———————, 1939. On oxidation, fermentation, vitamins, health and disease. Williams and Wilkins Co., Baltimore, 109 pp.

(80) Turner, John S., 1937. On the relation between respiration and fermentation in yeast and the higher plants. A review of our knowledge of the effect of iodoacetate on the metabolism of plants. New Phytol., 36: 142–169.

(81) ———————, 1938. The respiratory metabolism of carrot tissue. II. The effect of sodium mono iodoacetate on the respiration and fermentation. New Phytol., 37: 289–311.

(82) Vickery, Hubert B., Pucher, George, W., Wakeman, Alfred J., and Leavenworth, Charles S., 1939. Chemical investigations of the rhubarb plant. Conn. Agr. Expt. Stn. Bull., 424, 157 pp.

(83) Virtanen, A. I., and Nordlund, M., 1934. Synthesis of sucrose in plant tissue. Biochem. Jr., 28: 1729–1732.

(84) Wood, J. G., 1941. Relations between respiration rate and metabolism of carbohydrate, protein, and organic acids in leaves. Australian Jr. Exp. Biol. & Med. Sci., 19: 313–321.

(85) Zimmerman, P. W., 1930. Oxygen requirements for root growth of cuttings in water. Am. Jr. Bot., 17: 842–861.

# The Early Development and Rate of Nutrient Uptake by Sugar Cane

By R. J. Borden

*Studies of the early development of a sugar cane crop and of the nature of its nutrient uptake provide basic information for the sugar cane agriculturist whose interest is in providing an optimum nutriment for his crop.*

*This present study shows some of the relationships in cane which was started at different times during the year and harvested at comparative growth stages thereafter. All parts of the crop have been periodically collected, weighed, and analyzed for their concentration of the three principal plant foods, and from the data obtained a picture of the rate of development and of nutrient uptake forms the principal basis for the ensuing presentation.*

An addition to the work of previous investigators who have studied the development and the uptake of nitrogen, phosphoric acid, and potash by the sugar cane plant can now be made from the results which have been summarized from our Project A 105—No. 132.* Although the data cover a period of only the first 12 months of growth of H 109 cane, this period is recognized as a critical one insofar as nutrient supply and absorption are concerned, and a better understanding of this early nutrient uptake should lead to a better knowledge of the rate at which sugar cane prefers to take up its mineralized plant food.

Since it was desirable to secure data to show the *total* uptake of N, $P_2O_5$, and $K_2O$, it was necessary to plan the investigation so that all vegetative growth including abscissed leaves and all roots could be recovered. This necessitated recourse to a controlled pot culture, and we made use of 16-inch diameter concrete pots, each filled with 52 pounds of a well-mixed soil, and located at Makiki for convenience in handling.

In order to avoid a bias on nutrient uptake, which can follow from the usual method of applying several doses of commercial fertilizer to growing cane, we made several trials before a satisfactory technique was found. Under natural soil conditions, nitrogen becomes available through a series of complex biological and chemical changes in the soil. Under the more artificial conditions of modern sugar cane growing, the natural supply of nitrogen is supplemented by several heavy applications of chemical nitrogen. When nitrification works on these natural supplies the plant gets its nitrogen gradually, but from the artificial supply it gets a large amount all at once, and if given this chance to gorge itself this fact may have a very different effect upon its natural rate of uptake, not only of its nitrogen but also of phosphate and potash.

As finally installed, we used a mixture of two-thirds Manoa soil and one-third compost, limestone, superphosphate, and muriate of potash with bentonite (50–50)

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* Prepared, planted, fertilized, harvested, and samples prepared by L. R. Smith, A. Y. Ching, Y. Yamasaki, and various Assistants-in-Training. All chemical analyses by H. M. Lee.

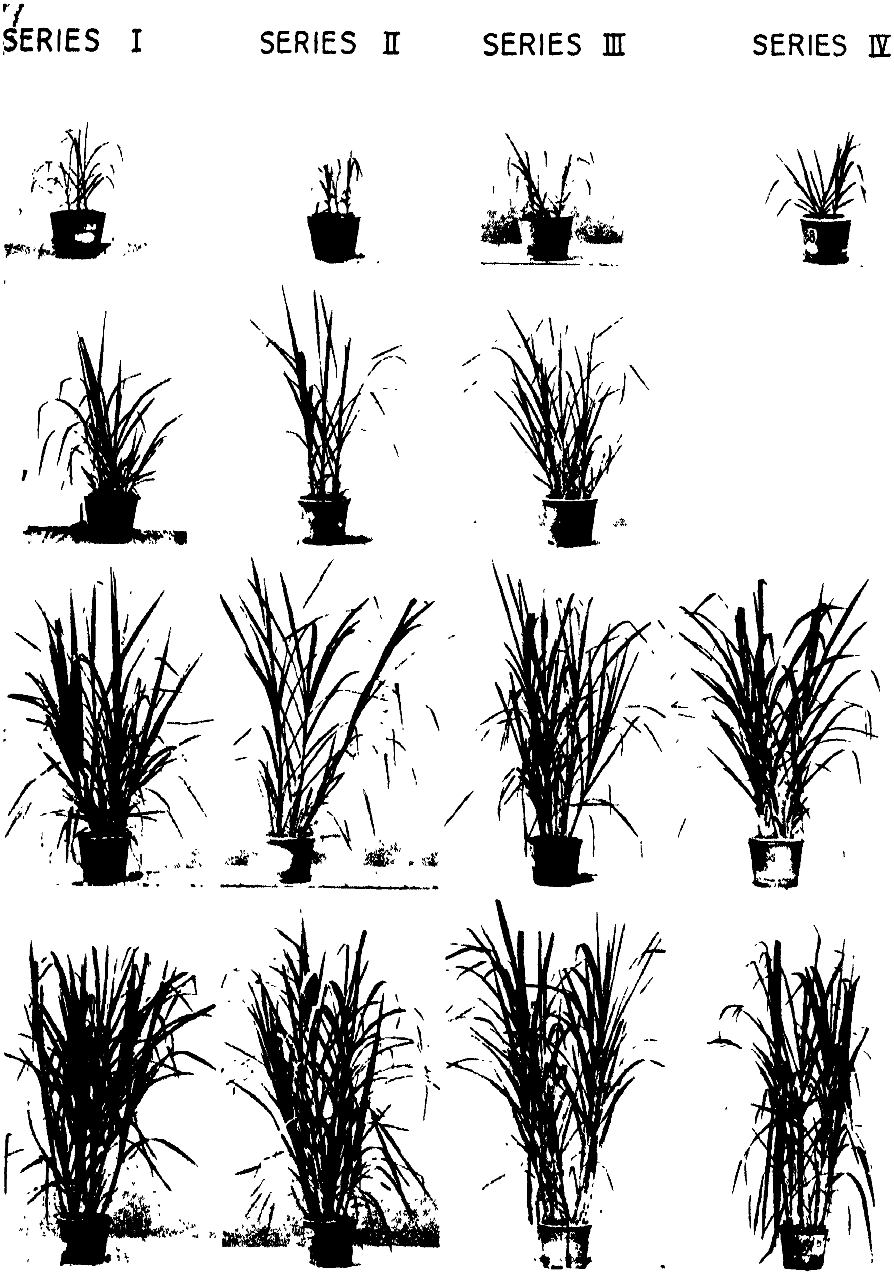


Fig. 1.

| First column | Second column | Third column | Fourth column |
|---|---|---|---|
| Series I | Series II | Series III | Series IV |
| Planted Nov. 16. | Planted Feb. 15. | Planted May 15. | Planted Aug. 15. |

Top row, 6th leaf-stage. Second row, 12th leaf-stage. Third row, 18th leaf-stage. Bottom row, 24th leaf-stage.

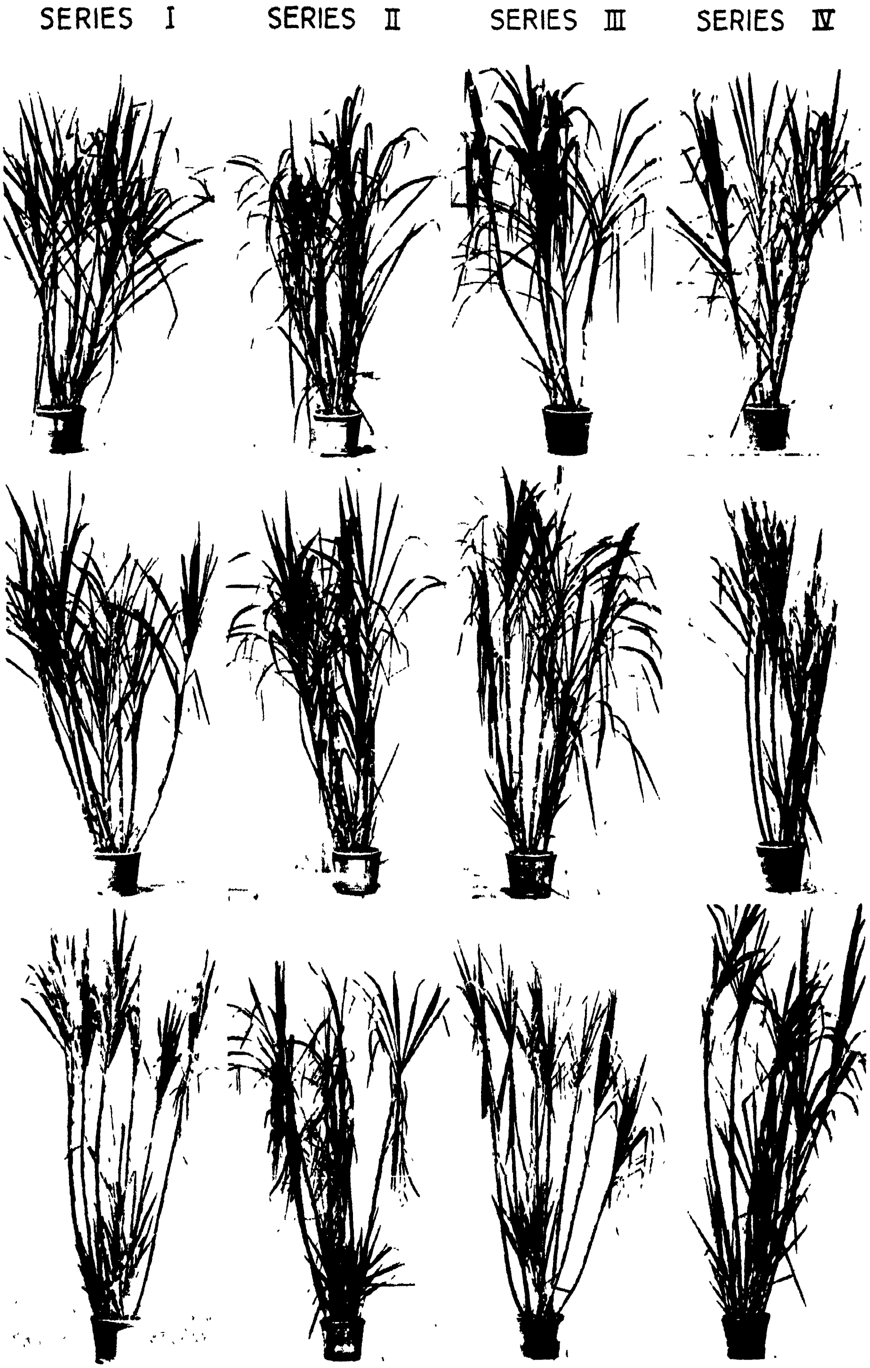


Fig. 1 (continued).
Top row, 30th leaf-stage. Middle row, 36th leaf-stage. Bottom row, 45th-48th leaf-stage.

to provide the basic medium in which the cuttings of H 109 were planted. Subsequently the nitrogen was supplied entirely from dried blood mixed with fresh soil and scratched into the surface of the soil in each pot at intervals of 500 day-degrees until the assumed total nitrogen requirement for the 12-month crop had been furnished. By this procedure it was believed that nitrogen uptake, which could not take place until this organic material was broken down by soil microorganisms, would be more nearly the natural uptake by the sugar cane crop. Subsequent observations of its growth showed that the cane was getting an adequate supply of nitrogen from these dried blood applications. Hence this plan was followed for four consecutive plantings or series: No. I planted on November 16, No. II on February 15, No. III on May 15, and No. IV on August 15—all in a soil medium which had been thoroughly mixed and potted before Series I was installed.

Harvesting periods for three pots in each series were originally specified at the unfolding of the 6th, 12th, 18th, 24th, 30th, 36th, and 42nd leaf blade, but a short time prior to the 42nd "leaf-stage" in Series I it was decided to carry the last group of three pots through to an age of 12 months before harvesting them.

Photographs of an average pot in each series were taken to record the comparative stages of development at each harvest. These are shown in Fig. 1, and should be studied with the following facts in mind:

ACTUAL DATES AND AGES (WEEKS) AT WHICH THE CONSECUTIVE LEAF STAGES WERE REACHED

| | Series I | | Series II | | Series III | | Series IV | |
|---|---|---|---|---|---|---|---|---|
| Leaf stage | Date | Age | Date | Age | Date | Age | Date | Age |
| 6th ............ | Jan. 25 | 10 | Apr. 18 | 9 | Jul. 3 | 7 | Oct. 7 | 7 |
| 12th ............ | Mar. 5 | 16 | May 24 | 14 | Aug. 7 | 12 | Nov. 18 | 13 |
| 18th ............ | Apr. 17 | 22 | Jul. 3 | 20 | Sept. 11 | 17 | Dec. 26 | 19 |
| 24th ............ | Jun. 3 | 29 | Aug. 7 | 25 | Oct. 28 | 24 | Feb. 13 | 26 |
| 30th ............ | Jul. 23 | 36 | Sept. 19 | 31 | Dec. 16 | 30 | Apr. 8 | 33 |
| 36th ............ | Aug. 28 | 41 | Oct. 28 | 37 | Jan. 27 | 36 | May 16 | 39 |
| 42nd ............ | — | — | — | — | — | — | Jun. 30 | 45 |
| 45 48th ......... | Nov. 18 | 52 | Feb. 13 | 52 | May 15 | 52 | Aug. 15 | 52 |

The total weights were secured of all "above-ground" parts which included tops, stalks, and all dry trash collected during the growth period concerned, and of all "below-ground" parts which included all roots and stubble and seed pieces below the ground level. The entire amounts produced in each pot were carefully ground up for samples that were subsequently dried and analyzed. The complete data are given in Tables IV to VII, and may be discussed therefrom or from the accompanying figures whereon the numerical data are plotted.

### *Concentration of Nutrients:*

The changes which took place in the concentration (%) of nutrients in the total dry weight as each successive leaf-stage was reached are shown in Table I.

### TABLE I
### AVERAGE CONCENTRATION (%) OF NUTRIENTS
(Average of 4 Series)

| | | Leaf stage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 6th | 12th | 18th | 24th | 30th | 36th | 42nd[1] | 45-48th |
| Above-ground parts | N | 1.81 | 1.55 | .93 | .70 | .59 | .49 | .45 | .34 |
| | $P_2O_5$ | .76 | .63 | .52 | .46 | .35 | .30 | .27 | .25 |
| | $K_2O$ | 3.08 | 2.69 | 2.16 | 1.52 | .98 | .61 | .59 | .34 |
| Below-ground parts | N | .74 | .81 | .68 | .65 | .66 | .65 | .56 | .59 |
| | $P_2O_5$ | .52 | .41 | .32 | .29 | .29 | .28 | .26 | .26 |
| | $K_2O$ | 1.39 | 1.24 | .94 | .55 | .32 | .27 | .32 | .23 |

[1] Only Series IV.

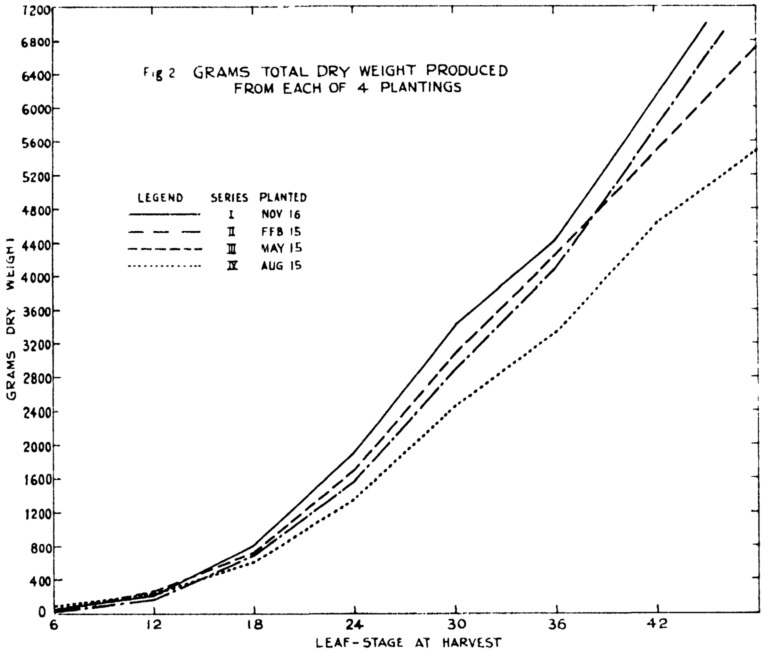
The percentage concentration of all nutrients decreased as the crop grew older. This decrease was considerably larger in the above-ground parts of the crop than in the roots and stubble that grew below ground. It is a factor that will need consideration in any attempt to determine critical concentration levels because a representative sample from a sugar cane crop will include stalks which have reached many different leaf-stages of development.

During the early stages, the concentration of nitrogen in the above-ground portions was higher than that in the parts below ground, but shortly after the 24th leaf was formed this relationship was reversed and thereafter the percentage of nitrogen found in the parts below ground was slightly the higher. This same reversal, however, was not found for the per cent potash or phosphate.

*Dry Weight:*

In studies of nutrient uptake, the percentage-composition figures can be the objects for incorrect interpretation unless the dry weight figures are also available, because the concentration of any one ingredient in the plant material is positively influenced by the extent to which the sample is diluted with other substances. Thus Fig. 2 is given to show the comparative amounts and rates in the production of total dry matter produced in each of the four series planted.

Except for Series IV planted in August, the dry weights at comparable stages of leaf development were perhaps not significantly different for the crops which were started in the different seasons, and the rates at which dry matter was produced were quite similar during their initial 12-month growth periods. The total production of dry matter was slow until the primary stalks had acquired their first 12 leaves; then, while they were forming another 6 leaves, the total dry weight doubled. This later figure, *i.e.*, at the 18th leaf-stage, was again doubled by the time 24 leaves had been produced, and this in turn had again almost doubled by the time the 30th leaf appeared. Thereafter, the rate at which the dry matter was formed continued, but without doubling, at about the same as between the 24th and 30th leaf-stages. Since during the first 9 months the average time between the unfolding of successive leaves was only 7 days, it is evident that this multiple period of increase in dry weight came between 84 and 210 days after planting, or approximately between the 3rd and 7th months; thus this is indicated as a most critical period in the development of the crop and one during which we infer that there should be no shortage of plant food or water if full returns are to be obtained.



| SERIES | | | | ACTUAL DATES HARVESTED | | | |
|---|---|---|---|---|---|---|---|---|
| I | 1/25 | 3/5 | 4/17 | 6/3 | 7/23 | 8/28 | – | 11/18 |
| II | 4/18 | 5/24 | 7/3 | 8/7 | 9/19 | 10/28 | – | 2/13 |
| III | 7/3 | 8/7 | 9/11 | 10/28 | 12/16 | 1/27 | – | 5/15 |
| IV | 10/7 | 11/18 | 12/26 | 2/13 | 4/8 | 5/16 | 6/30 | 8/15 |

Fig. 2.

*Uptake of Nitrogen:*

All series were being supplied with nitrogen, from dried blood at 500 day-degree intervals until shortly after the 36th leaf blade had unfolded, at 30 grams per pot for the first three and at 60 grams for the next five applications. In Fig. 3 there is shown a considerable similarity between the four series of crops in the totals and rates of uptake of their nitrogen. Thus a cane crop which had not reached its 18th leaf-stage (generally between 4 and 5 months) took up nitrogen from an equivalent supply at very similar rates and amounts. Between its 18th and 30th leaf-stage, the rates of nitrogen absorption were much faster than before this growth stage, and except for Series II which encountered the effects of the winter months at this time, these rates were again quite similar during the other seasons of the year. The effect of this interaction between the 18th-30th leaf-stage of growth and the winter months, upon the total nitrogen uptake, is primarily due to the decreased amount of dry matter, for the percentage of nitrogen in the trash, tops, and cane was actually higher than in the other three series during this season.

After the 30th leaf-stage was reached, the nitrogen absorption rates for Series I, II, and III slowed up and were again quite similar to those of the early stages; and at the 36th leaf-stage the total amounts which had been taken up by each series were again not very different.

*Uptake of Phosphate:*

The total amounts and the rates at which phosphate was absorbed, although lower and slower than for nitrogen, show a certain degree of parallelism. (Com-

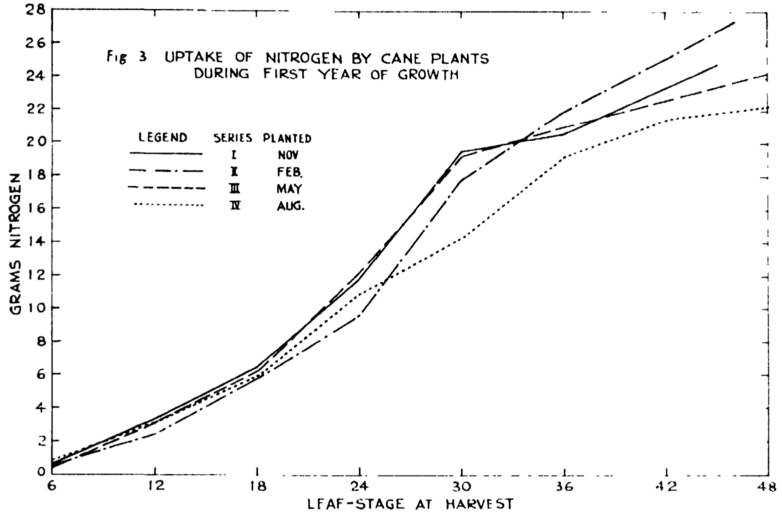


Fig 3 UPTAKE OF NITROGEN BY CANE PLANTS DURING FIRST YEAR OF GROWTH
LEGEND SERIES PLANTED
I NOV
II FEB.
III MAY
IV AUG.
GRAMS NITROGEN
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
6
12
18
24
30
36
42
48
LEAF-STAGE AT HARVEST

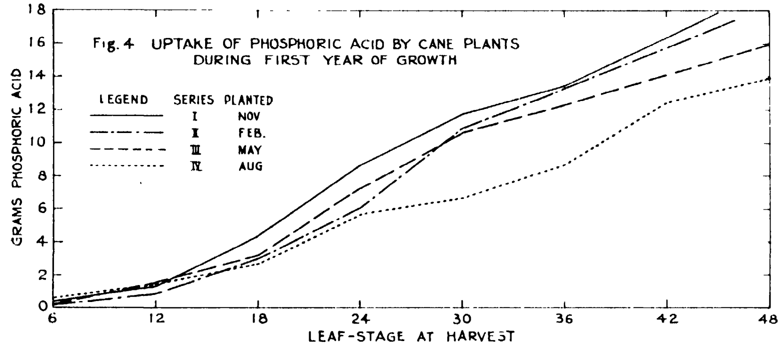


Fig. 4 UPTAKE OF PHOSPHORIC ACID BY CANE PLANTS DURING FIRST YEAR OF GROWTH
LEGEND SERIES PLANTED
I NOV
II FEB.
III MAY
IV AUG
GRAMS PHOSPHORIC ACID
0
2
4
6
8
10
12
14
16
18
6
12
18
24
30
36
42
48
LEAF-STAGE AT HARVEST

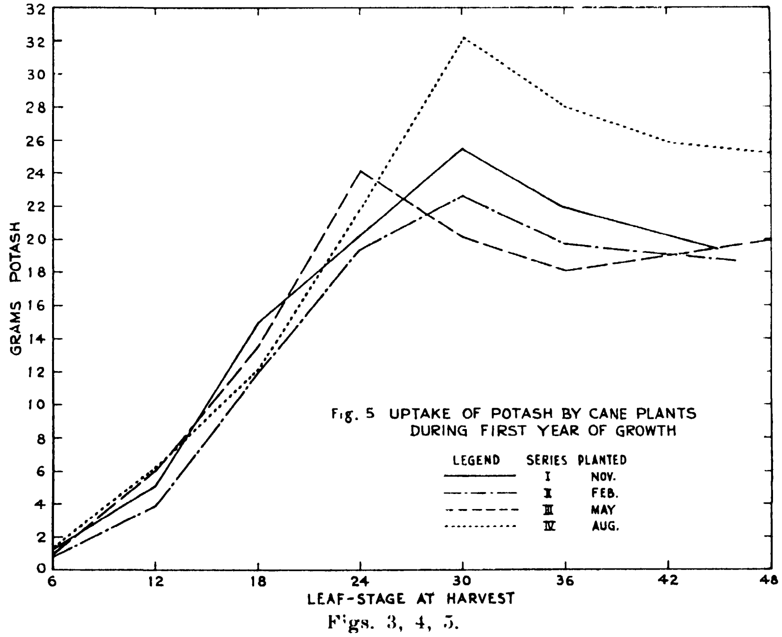


Fig. 5 UPTAKE OF POTASH BY CANE PLANTS DURING FIRST YEAR OF GROWTH
LEGEND SERIES PLANTED
I NOV.
II FEB.
III MAY
IV AUG.
GRAMS POTASH
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
32
6
12
18
24
30
36
42
48
LEAF-STAGE AT HARVEST

Figs. 3, 4, 5.

pare Fig. 4 with Fig. 3.) The rate of phosphate absorption during the early growth period, while only about half as fast as for nitrogen, was quite constant and without further increase after the crop had reached its 12th leaf-stage.

The total phosphate uptake by plants in Series IV fell below that of the other three series after the 12th leaf-stage had been passed. This was largely due to the lower yield of dry matter although at the 30th and 36th leaf-stages the percentage of $P_2O_5$ in the dry matter of the above-ground parts of this series was also lower.

*Uptake of Potash* (Fig. 5):

The early uptake of potash was at a faster rate than the corresponding uptake of nitrogen, not only between the unfolding of the 6th and 12th leaves but also immediately thereafter, until 24 or 30 leaves had been grown.

Unlike both nitrogen and phosphate, all four series show a sharp break in their potash curves in the second halves of their growth periods. This break occurred after the 24th leaf-stage in Series III but not until the 30th leaf-stage in the other three series. Since the 24th leaf-stage for Series III was reached in late October, it appears that the less-favorable or winter climatic conditions immediately thereafter may have been responsible for this somewhat earlier loss of potash.

The actual loss of potash from these crops during their later growth stages was a loss which took place from the above-ground parts only, for the below-ground portions did not show corresponding losses. Since all dry trash was saved and included in the samples analyzed, this loss of potash cannot be explained as an actual loss of some of the dry matter. Hence it appears that potash has actually moved out of the cane plant—perhaps back into the soil as some plant investigators have suggested.

*Average Amounts and Rates of Absorption:*

In Figs. 6 and 7 we have brought together all the data from Figs. 3, 4, and 5 to show: (*a*) the comparative amounts of nitrogen, phosphate, and potash that were found in the total dry matter which had been produced at successive leaf stages of development, and (*b*) the comparative rates at which these three nutrients were absorbed. They illustrate, quite simply, the general relationships already discussed.

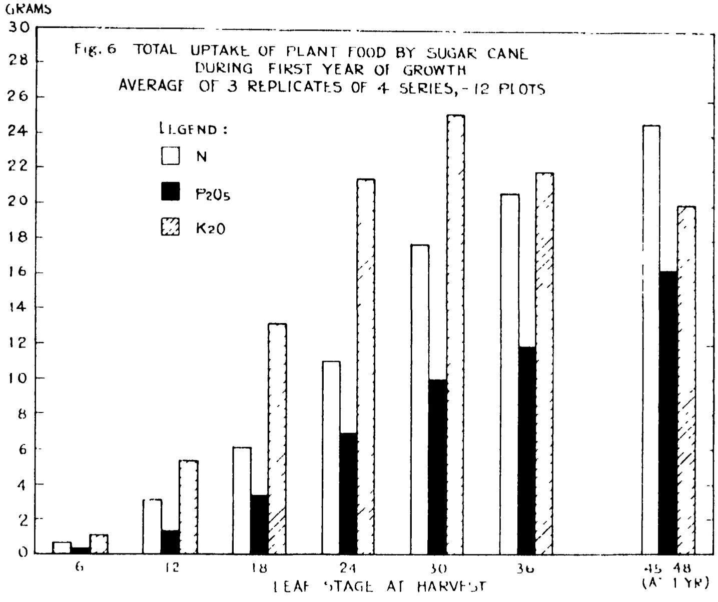
*Proportions Found Below and Above Ground:*

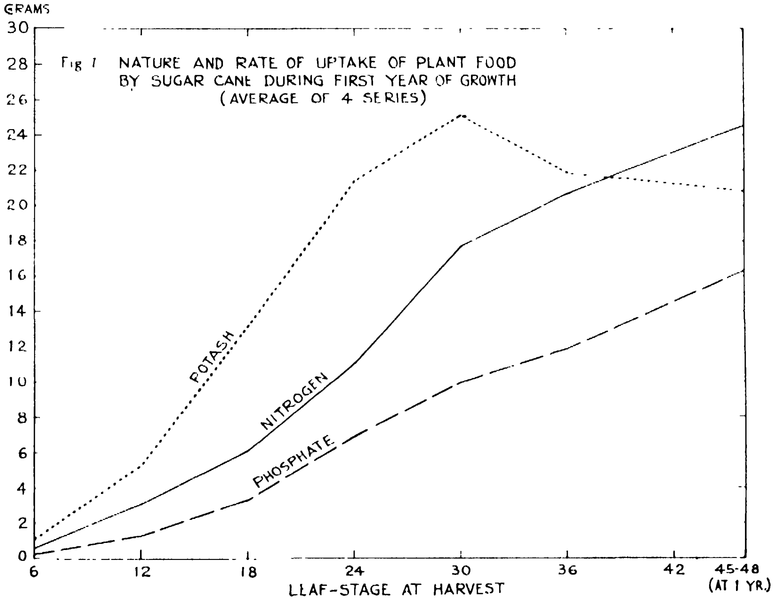
The figures in Table II show the approximate proportions of the total dry weight as found both below and above ground at successive harvests, and the corresponding proportions in the concentration of the three major nutrients studied.

TABLE II

PROPORTION OF BELOW-GROUND TO ABOVE-GROUND PARTS AT SUCCESSIVE HARVESTS

| Leaf-stage | In total dry wt. | In concentration of nutrients | | |
|---|---|---|---|---|
| | | N | $P_2O_5$ | $K_2O$ |
| 6th | 1.91 | .41 | .69 | .45 |
| 12th | .40 | .52 | .64 | .46 |
| 18th | .32 | .74 | .61 | .44 |
| 24th | .23 | .93 | .63 | .36 |
| 30th | .20 | 1.15 | .83 | .32 |
| 36th | .19 | 1.32 | .94 | .44 |
| 45–48th | .18 | 1.72 | 1.04 | .66 |





Figs. 6, 7.

These figures may be found useful in estimating the amounts of nutrients in the roots and stubble, which would usually be left in the field after harvesting, from actual measurements of nutrients which could be more easily determined from samples of the above-ground parts. For example: At the 36th leaf-stage, the amounts of roots, stubble, and seed pieces in our study was .19 of the amount of dry matter produced above ground. Thus if it were known that the above-ground crop averaged, let us say 15 tons per acre of total dry weight (which would be equivalent to approximately 60 tons green weight, made up of about 46 tons of stalks and 14 tons of tops and trash), it could be assumed that .19 of 15 tons or 2.85 tons of dry weight would be left in the soil. Then, if an analysis of samples of the dry weight of the above-ground parts were to show .49 per cent N, it would be assumed that their corresponding below-ground parts would average about 1.32 times .49 per cent or .65 per cent N. Thus this 2.85 tons of dry matter at .65 per cent N would leave something in the order of 37 pounds of nitrogen behind in the soil at harvest, whereas the remainder, some 12.15 tons of stalks and leaves at .49 per cent N, would mean that about 119 pounds of nitrogen would leave the field as the crop was taken away.

In a similar manner the approximate amounts of $P_2O_5$ and $K_2O$ which would be left behind in the soil would be estimated from an analysis of the above-ground parts harvested. Thus if these showed .30 per cent $P_2O_5$ and .61 per cent $K_2O$, we would estimate that these 2.85 tons of dry weight below ground averaged .94 times .30 per cent or .28 per cent $P_2O_5$, and .44 times .61 per cent or .27 per cent $K_2O$, and so would leave behind some 16 pounds of phosphate and 15 pounds of potash, while some 73 pounds of phosphate and 148 pounds of potash were being taken away.

A segregation of the "above-ground" parts at each harvest, to show the percentages of their total dry weights represented in (*a*) the millable cane, (*b*) the green tops, and (*c*) all trash or dry leaves which had accumulated, is given in Table III.

TABLE III
SEGREGATION OF TOTAL DRY WEIGHT AS FOUND IN THE ABOVE-GROUND PARTS

| | Approximate per cent of total | | |
|---|---|---|---|
| Leaf-stage | As cane | As tops | As trash |
| 6th | — | 100 | — |
| 12th | — | 100 | — |
| 18th | 28 | 72 | — |
| 24th | 42 | 51 | 7 |
| 30th | 52 | 34 | 14 |
| 36th | 55 | 29 | 16 |
| 45–48th | 58 | 15 | 27 |

The millable cane at the final harvest amounted to only 58 per cent of the total dry weight which had been produced above ground. The percentage represented by the tops decreased as the crop grew older and at the end of a year was not unlike the percentage of tops we have found in previous studies. At the time the 18th leaf appeared, there had been no dropping off of the old leaves, although some of them had undoubtedly ceased to function at this time, and perhaps their dry weight should have been deducted from "tops" and included as "trash"; in all subsequent harvests all dry leaves were so included. In connection with the trash accumulation, we find that this part of the crop amounts to fully one-quarter of the total dry matter produced above ground at the age of 12 months.

## SUMMARY

From periodic harvests of sugar cane which was started in different seasons, we have recorded the rates at which the crop has developed, and the N-P-K composition of both the below- and above-ground portions. From these data we find the following of sufficient interest to summarize:

1. The concentration of nitrogen, phosphate, and potash has decreased with an increase in age.

2. The rates at which dry matter was produced were quite similar except for the crop which was planted in August. Apparently the winter weather influenced this planting at the age when it should have been doubling its weight.

3. The most rapid uptake of nitrogen occurred between the appearance of the 18th and 30th leaves—roughly from 4 to 9 months. Winter weather during this growth period decreased the rate of nitrogen absorption.

4. Phosphate absorption was quite constant after the crop was well under way.

5. In the early stages, potash was taken up at a very rapid rate. About midway in the growth period, an actual loss of potash from the plant tissues took place.

6. A possible utilization of the data secured may be made in estimating amounts of the major nutrients in those parts of a cane crop which develop below ground.

## TABLE IV

### SUMMARY OF YIELDS AND ANALYSES OF SERIES I—PLANTED NOV. 16

(Averages of 3 Replicates at Each Harvest)

| Harvested | Leaf-stage<br>Date<br>Age (weeks) | 6th<br>Jan. 25<br>10 | 12th<br>Mar. 5<br>16 | 18th<br>Apr. 17<br>22 | 24th<br>Jun. 3<br>29 | 30th<br>Jul. 23<br>36 | 36th<br>Aug. 28<br>41 | 45th<br>Nov. 18<br>52 |
|---|---|---|---|---|---|---|---|---|
| Above-ground parts (tops, cane and trash) | Grams dry wt. | 24 | 157 | 606 | 1534 | 2817 | 3644 | 5800 |
| | % N ........ | 1.70 | 1.80 | .90 | .62 | .56 | .43 | .31 |
| | % $P_2O_5$ ..... | .78 | .70 | .63 | .48 | .36 | .30 | .25 |
| | % $K_2O$ ...... | 3.01 | 2.68 | 2.15 | 1.24 | .85 | .55 | .29 |
| | Gms. N ...... | .41 | 2.83 | 5.45 | 9.51 | 15.78 | 15.67 | 17.98 |
| | Gms. $P_2O_5$ ... | .19 | 1.10 | 3.82 | 7.36 | 10.14 | 10.93 | 14.50 |
| | Gms. $K_2O$ ... | .72 | 4.21 | 13.03 | 19.02 | 23.94 | 20.04 | 16.82 |
| Below-ground parts (roots, stubble, and seed piece) | Grams dry wt. | 35 | 71 | 205 | 365 | 600 | 803 | 1215 |
| | % N ........ | .79 | .81 | .55 | .65 | .63 | .62 | .57 |
| | % $P_2O_5$ ..... | .53 | .42 | .32 | .35 | .28 | .32 | .28 |
| | % $K_2O$ ...... | 1.37 | 1.32 | .99 | .35 | .27 | .23 | .22 |
| | Gms. N ...... | .28 | .58 | 1.13 | 2.37 | 3.78 | 4.98 | 6.93 |
| | Gms. $P_2O_5$ ... | .19 | .30 | .66 | 1.28 | 1.68 | 2.57 | 3.40 |
| | Gms. $K_2O$ ... | .48 | .94 | 2.03 | 1.28 | 1.62 | 1.85 | 2.67 |
| Totals (entire crop) | Grams dry wt. | 59 | 228 | 811 | 1899 | 3417 | 4447 | 7015 |
| | Gms. N ...... | .69 | 3.41 | 6.58 | 11.88 | 19.56 | 20.65 | 24.91 |
| | Gms. $P_2O_5$ ... | .38 | 1.40 | 4.48 | 8.64 | 11.82 | 13.50 | 17.90 |
| | Gms. $K_2O$ ... | 1.20 | 5.15 | 15.06 | 20.30 | 25.56 | 21.89 | 19.49 |

## TABLE V

### SUMMARY OF YIELDS AND ANALYSES OF SERIES II—PLANTED FEB. 15

(Averages of 3 Replicates at Each Harvest)

| Harvested | Leaf-stage | 6th | 12th | 18th | 24th | 30th | 36th | 46th |
|---|---|---|---|---|---|---|---|---|
| | Date | Apr. 18 | May 24 | Jul. 3 | Aug. 7 | Sept. 19 | Oct. 28 | Feb. 13 |
| | Age (weeks) | 9 | 14 | 20 | 25 | 31 | 37 | 52 |
| Above-ground parts (tops, cane and trash) | Grams dry wt. | 14 | 116 | 481 | 1227 | 2344 | 3408 | 5894 |
| | % N ........ | 1.84 | 1.68 | .82 | .61 | .60 | .50 | .34 |
| | % $P_2O_5$ ..... | .79 | .65 | .47 | .42 | .39 | .33 | .25 |
| | % $K_2O$ ...... | 3.17 | 2.85 | 2.09 | 1.41 | .90 | .53 | .28 |
| | Gms. N ...... | .26 | 1.95 | 3.94 | 7.48 | 14.06 | 17.04 | 20.04 |
| | Gms. $P_2O_5$ ... | .11 | .75 | 2.26 | 5.15 | 9.14 | 11.25 | 14.74 |
| | Gms. $K_2O$ ... | .44 | 3.31 | 10.05 | 17.30 | 21.10 | 18.06 | 16.50 |
| Below-ground parts (roots, stubble, and seed piece) | Grams dry wt. | 34 | 59 | 220 | 336 | 533 | 678 | 1054 |
| | % N ........ | .84 | .81 | .87 | .61 | .71 | .73 | .68 |
| | % $P_2O_5$ ..... | .48 | .40 | .35 | .28 | .34 | .31 | .27 |
| | % $K_2O$ ...... | 1.29 | 1.14 | .92 | .64 | .29 | .25 | .21 |
| | Gms. N ...... | .29 | .48 | 1.91 | 2.05 | 3.78 | 4.95 | 7.17 |
| | Gms. $P_2O_5$ ... | .16 | .24 | .77 | .94 | 1.81 | 2.10 | 2.85 |
| | Gms. $K_2O$ ... | .44 | .67 | 2.02 | 2.15 | 1.55 | 1.70 | 2.21 |
| Totals (entire crop) | Grams dry wt. | 48 | 175 | 701 | 1563 | 2877 | 4086 | 6948 |
| | Gms. N ...... | .55 | 2.43 | 5.85 | 9.53 | 17.84 | 21.99 | 27.21 |
| | Gms. $P_2O_5$ ... | .27 | .99 | 3.03 | 6.09 | 10.95 | 13.35 | 17.59 |
| | Gms. $K_2O$ ... | .88 | 3.98 | 12.07 | 19.45 | 22.65 | 19.76 | 18.71 |

## TABLE VI

### SUMMARY OF YIELDS AND ANALYSES OF SERIES III—PLANTED MAY 15

(Averages of 3 Replicates at Each Harvest)

| Harvested | Leaf-stage | 6th | 12th | 18th | 24th | 30th | 36th | 48th |
|---|---|---|---|---|---|---|---|---|
| | Date | Jul. 3 | Aug. 7 | Sept. 11 | Oct. 28 | Dec. 16 | Jan. 27 | May 15 |
| | Age (weeks) | 7 | 12 | 17 | 24 | 30 | 36 | 52 |
| Above-ground parts (tops, cane and trash) | Grams dry wt. | 13 | 208 | 565 | 1398 | 2596 | 3599 | 5787 |
| | % N ........ | 1.88 | 1.32 | .95 | .74 | .61 | .47 | .33 |
| | % $P_2O_5$ ..... | .79 | .61 | .50 | .47 | .36 | .30 | .24 |
| | % $K_2O$ ...... | 3.08 | 2.44 | 2.18 | 1.64 | .72 | .46 | .31 |
| | Gms. N ...... | .24 | 2.75 | 5.37 | 10.28 | 15.84 | 16.92 | 19.10 |
| | Gms. $P_2O_5$ ... | .10 | 1.27 | 2.82 | 6.53 | 9.35 | 10.80 | 13.89 |
| | Gms. $K_2O$ ... | .40 | 5.08 | 12.32 | 22.78 | 18.69 | 16.56 | 17.94 |
| Below-ground parts (roots, stubble, and seed piece) | Grams dry wt. | 34 | 71 | 141 | 285 | 492 | 672 | 904 |
| | % N ........ | .62 | .82 | .62 | .68 | .69 | .62 | .56 |
| | % $P_2O_5$ ..... | .55 | .40 | .32 | .26 | .26 | .23 | .23 |
| | % $K_2O$ ...... | 1.59 | 1.34 | .96 | .48 | .31 | .24 | .22 |
| | Gms. N ...... | .21 | .58 | .87 | 1.94 | 3.39 | 4.17 | 5.06 |
| | Gms. $P_2O_5$ ... | .19 | .28 | .45 | .74 | 1.28 | 1.55 | 2.08 |
| | Gms. $K_2O$ ... | .54 | .95 | 1.35 | 1.37 | 1.53 | 1.61 | 1.99 |
| Totals (entire crop) | Grams dry wt. | 47 | 279 | 706 | 1683 | 3088 | 4271 | 6691 |
| | Gms. N ...... | .45 | 3.33 | 6.24 | 12.22 | 19.23 | 21.09 | 24.16 |
| | Gms. $P_2O_5$ ... | .29 | 1.55 | 3.27 | 7.27 | 10.63 | 12.35 | 15.97 |
| | Gms. $K_2O$ ... | .94 | 6.03 | 13.67 | 24.15 | 20.22 | 18.17 | 19.93 |

## TABLE VII

### SUMMARY OF YIELDS AND ANALYSES OF SERIES IV—PLANTED AUG. 15

(Averages of 3 Replicates at Each Harvest)

| | Harvested | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Leaf-stage | 6th | 12th | 18th | 24th | 30th | 36th | 42nd | 48th |
| | Date | Oct. 7 | Nov. 18 | Dec. 26 | Feb. 13 | Apr. 8 | May 16 | Jun. 30 | Aug. 15 |
| | Age (weeks) | 7 | 13 | 19 | 26 | 33 | 39 | 45 | 52 |
| Above-ground parts (tops, cane and trash) | Grams dry wt. | 28 | 199 | 495 | 1123 | 2113 | 2924 | 4113 | 4811 |
| | % N ......... | 1.83 | 1.39 | 1.03 | .84 | .58 | .57 | .45 | .38 |
| | % $P_2O_5$ ...... | .69 | .55 | .48 | .46 | .27 | .26 | .27 | .25 |
| | % $K_2O$ ...... | 3.07 | 2.79 | 2.23 | 1.80 | 1.46 | .91 | .59 | .49 |
| | Gms. N ...... | .51 | 2.77 | 5.10 | 9.43 | 12.26 | 16.67 | 18.51 | 18.28 |
| | Gms. $P_2O_5$ ... | .19 | 1.09 | 2.38 | 5.17 | 5.71 | 7.60 | 11.11 | 12.03 |
| | Gms. $K_2O$ .... | .86 | 5.55 | 11.04 | 20.21 | 30.85 | 26.61 | 24.27 | 23.57 |
| Below-ground parts (roots, stubble, and seed piece) | Grams dry wt. | 48 | 69 | 119 | 226 | 339 | 400 | 526 | 762 |
| | % N ......... | .71 | .81 | .68 | .66 | .62 | .64 | .56 | .53 |
| | % $P_2O_5$ ...... | .53 | .40 | .28 | .26 | .27 | .26 | .26 | .25 |
| | % $K_2O$ ...... | 1.30 | 1.14 | .89 | .73 | .39 | .36 | .32 | .26 |
| | Gms. N ...... | .34 | .56 | .81 | 1.49 | 2.10 | 2.56 | 2.95 | 4.04 |
| | Gms. $P_2O_5$ ... | .25 | .28 | .33 | .59 | .92 | 1.04 | 1.37 | 1.91 |
| | Gms. $K_2O$ .... | .62 | .79 | 1.06 | 1.65 | 1.32 | 1.44 | 1.68 | 1.98 |
| Totals (entire crop) | Grams dry wt. | 76 | 268 | 614 | 1349 | 2452 | 3324 | 4639 | 5573 |
| | Gms. N ...... | .85 | 3.33 | 5.91 | 10.92 | 14.36 | 19.23 | 21.46 | 22.32 |
| | Gms. $P_2O_5$ ... | .44 | 1.37 | 2.71 | 5.76 | 6.63 | 8.64 | 12.48 | 13.94 |
| | Gms. $K_2O$ .... | 1.48 | 6.34 | 12.10 | 21.86 | 32.17 | 28.05 | 25.95 | 25.55 |

# Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 16, 1943, TO DECEMBER 15, 1943

| Date | Per Pound | Per Ton | Remarks |
|---|---|---|---|
| Sept. 16 - Dec. 15, 1943 | 3.74¢ | $74.80 | Philippines |

THE HAWAIIAN

PLANTERS' RECORD

Vol. XLVIII SECOND QUARTER 1944 No. 2

*A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.*

# Fusarium Disease of the Prickly Pear

By C. W. Carpenter

*A destructive disease of the common prickly pear, generally known as "panini" in Hawaii, is discussed. The disease, first reported at Kekaha, Kauai, has been investigated in cooperation with the Territorial Board of Agriculture and Forestry, and the latter has approved the transmission of the causal agent, a fungus, to localities where the panini is a pest. Large and small panini plants have collapsed in from two to five weeks after inoculation with the parasitic fungus, a variety of* Fusarium oxysporum.

A disease of the common prickly pear (*Opuntia megacantha*) which was reported to be very destructive at Kekaha Sugar Company, Ltd. was pointed out to several staff members of the Experiment Station, H.S.P.A. in November 1943, by L. A. Faye, Manager. Cladodes, usually referred to as pads or joints, of the affected plants were collected by Steven Au and submitted by D. T. Fullaway for diagnosis.

Various diseases of cacti have been reported rather extensively in literature but none appears identical with the disease discussed herein. The symptoms are not particularly distinctive—a progressive softening of the entire pad accompanied by a change of the normal green to gray and fuscous with ultimate collapse of the pad which falls to the ground. At times considerable exudate oozes from the ruptured surfaces and dries as a firm gum, and secondary rot organisms (bacteria) may hasten the destruction, often developing gas which swells the affected area.

Mr. Fullaway was advised to inoculate healthy plants with tissue and juice from the diseased material to determine if the disease was infectious. These direct inoculations and others made subsequently by him and by J. P. Martin and C. G. Lennox were positive in a sufficiently large percentage to establish the infectious nature of the disease.

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In the meantime a *Fusarium* sp. (fungus) and two strains of bacteria were isolated in pure culture from the original specimens. Healthy pads, brought to the laboratory by Mr. Fullaway, were inoculated with the three organisms, separately, and in all combinations. Rotting, typical of the original material and of the direct inoculations, developed only when the Fusarium was present in the inoculum. In a subsequent experiment one hundred per cent positive results, secured from inoculations of detached pads with the Fusarium, demonstrated that this fungus was capable of producing the symptoms (Figs. 1 and 2). Control inoculations made with sterile distilled water were uniformly without effect. Numerous inoculations

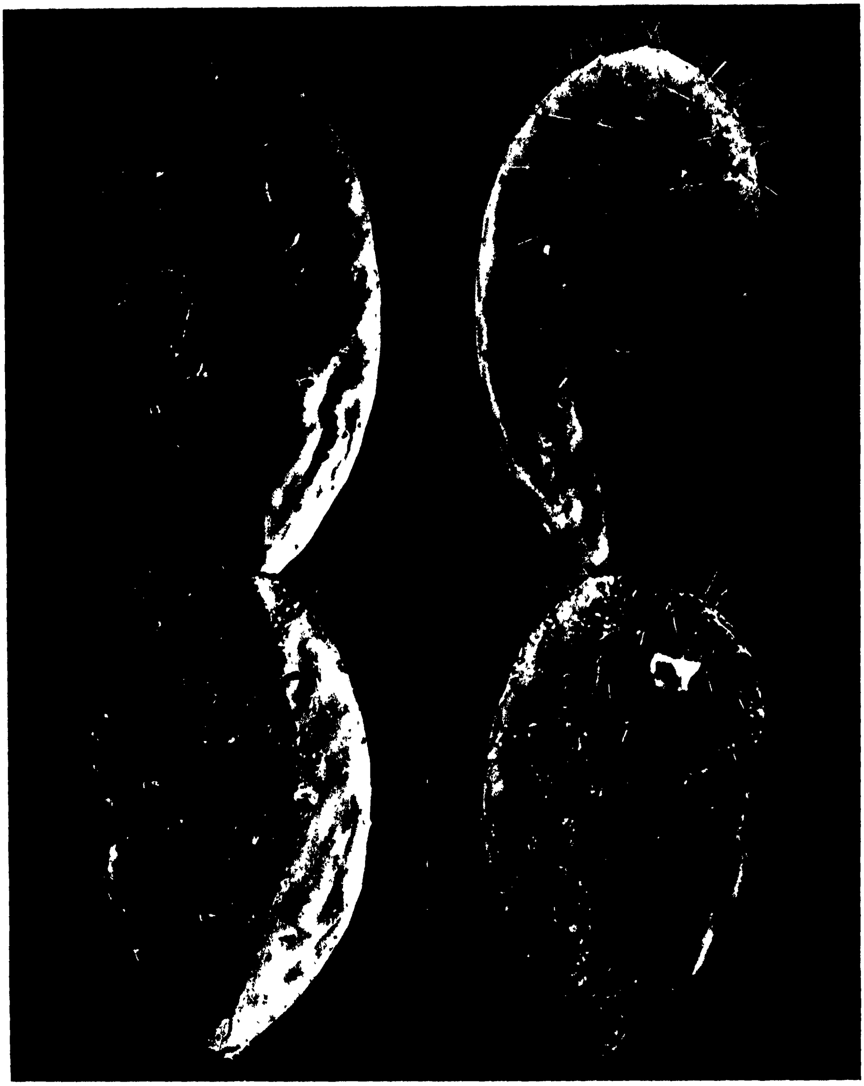

**Fig. 1.** Upper and lower surfaces of two pads of prickly pear two weeks after inoculation with *Fusarium oxysporum* var. at three points on each pad (at the left). The dark, rotted area has almost reached the six control punctures. At the right, lower surfaces of the same pads.

of twelve large and small pear plants growing on the slope of Punchbowl Crater were then made hypodermically with spore suspensions of pure cultures of the reisolated Fusarium; control inoculations with sterile distilled water were made at various points on four other plants. Within ten days it was evident that without exception the Fusarium had infected the pads at every inoculation point while at no time did the control inoculations show any sign of infection. In the majority of cases the pads inoculated with the Fusarium were in three weeks almost completely rotted and dropping off, while the smaller plants consisting of three to five pads were rotted to the ground.

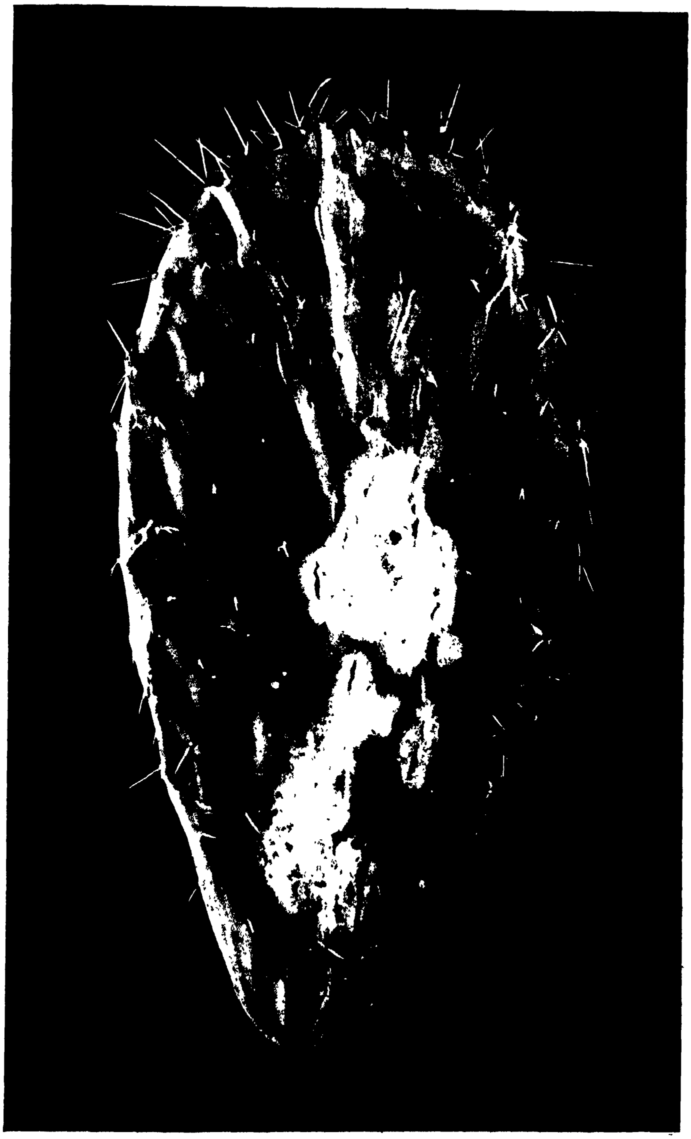

Fig. 2. The lower surface of an inoculated pad of prickly pear; the mycelium of *Fusarium oxysporum* var. has grown through the pad and formed spores.

McLaughlin (1) described a necrotic rot disease of *Cereus Schottii* occurring in Mexico and Arizona and concluded that it was caused by an undetermined variety of *Fusarium oxysporum*. Successful inoculations of *C. Schottii* and of a prickly pear of the Englemannii group were reported. Pasinetti and Buzzati-Traverso (2) discussed two species of Fusarium as wound parasites of cacti in Italy: *F. cactacearum* caused a basal dry rot of *Thelocactus nidulans* and *F. cacti-maxoni* similarly attacked *Cactus maxoni*. Another species apparently from cactus, *F. opuntiarum* Speg., was reduced to synonomy with *F. oxysporum* by Wollenweber and Reinking (3, p. 330).

The Fusarium in the present studies, observed to be at least a wound parasite of the prickly pear, was identified as a variety of *F. oxysporum* after growing it in pure culture on sterile cotton stems, Panicum culms, rice, and nutrient agar containing one-half per cent neopeptone (Difco). On the rice medium a faint aromatic odor suggesting lilac, an odor characteristic of several species of the Section Elegans of the Genus Fusarium, was noticed. As mycologists well know, extensive and critical comparative studies are required to identify species and varieties in this difficult genus. In the present species as well as in most species of this genus the microconidia are of very slight diagnostic value; on the other hand the size and shape of the macroconidia from cultures in suitable stages of development are characteristic of the Sections and in many cases specifically of great diagnostic value. The macroconidia from pionnotes (spore slime) and sporodochia (fruiting bodies), illustrated in Fig. 3, are much larger than recorded by McLaughlin, being approximately three times as long in the case of the four-septate spores: 35–55 x 4.0–5.0 microns. Four-septate forms were common as was also recorded by McLaughlin. The rather meagre symptoms of the disease as recorded by the latter on an Opuntia species do not closely resemble those of the disease under study; this lack of harmony together with the difference in host plants and the great discrepancy in the size of the macroconidia of the Fusaria indicate that the two diseases are distinct.

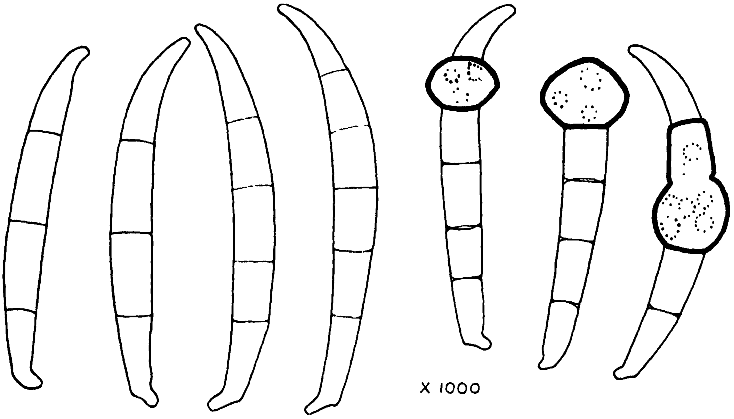

**Fig. 3.** Macroconidia and thick-walled resistant spores, conidio-chlamydospores, of *Fusarium oxysporum* var. Such spores are produced in abundance on the cactus as well as in cultures.

The *Section Elegans* of the *Genus Fusarium* of which the local *F. oxysporum* var. is a member includes many important plant parasites which cause serious wilt diseases, e.g., *F. oxysporum,* Irish potato wilt; *F. bulbigenum* var. *lycopersici,* tomato wilt; and *F. vasinfectum,* cotton wilt.

The prickly pear in Hawaii as well as elsewhere is an important forage plant in arid sections. In drought the tender young pads are the life-saving sources of succulent food and water for livestock. In some arid sections of Hawaii the prickly pear, and the dew and misty rains are such important sources, if not the only sources of water, that cattle are reported to reach maturity without learning to drink; they will take water only by lapping it from moist surfaces in the paddocks and in trans-channel shipment to market.

In more fertile sections of the Islands the prickly pear is a detested weed encroaching upon large areas of the best land and rendering them useless for cultivation or pasturage. In such localities any disease of the cactus is welcomed as a possible means of restricting its spread or of killing it. What ultimate effect the Fusarium disease may have on this plant in Hawaii cannot be foretold.

## LITERATURE CITED

(1) McLaughlin, A. M., 1934. A Fusarium disease of Cereus schottii. Phytopathology, 24: 495–506.

(2) Pasinetti, L., and Buzzati-Traverso, A., 1935. On certain forms of gangrene in Cactaceae caused by new micromycetes and by a bacterium. Nuovo G. bot. ital. N.S., 42: 89–123. (Reviewed in Review Applied Mycology, 14: 764–765, 1935).

(3) Wollenweber, H. W., and Reinking, O. A., 1935. Die Fusarien. Paul Parey, Berlin, 1935, 355 pages.

# Crop Relationships With Special Reference to Nitrogen Efficiency

By R. J. Borden

*Six years of results from well-replicated nitrogen experiments have afforded data for a study of some of the involved relationships which can be useful in planning field practices, especially in judging the efficiency we are securing from applications of nitrogen fertilizer. Thus comparisons with some of their associations are offered between plant crops and ratoons, between different seasons of starting crops, of per-acre nitrogen applications, and of season and age at harvest. Yield groups are examined for differences which may be contributory factors and for evidence of their nitrogen utilization, and finally the suggested efficiency values in terms of nitrogen per month and per ton of cane are examined for confirmation of amounts previously indicated.*

We are often asked for information concerned with the effects which various cropping practices can exert upon optimum sugar yields, and a specific answer is exceedingly difficult because of the large number of contributory factors which may not always be subject to identification and measurement. Perhaps then, if we could examine reliable data which have come from a sufficiently large number of well-distributed sugar cane areas, we might find in the averaged measurements which are involved, indications of some of the relationships we are looking for. The usefulness of such averaged measurements to the individual plantation man will be first in indicating what specific deviations occur in similar measurements in his records, and then in rationalizing reasons therefor. Thus they will focus his attention on certain figures which are related to an average criterion of efficiency, and lead him to look for the real cause of the larger deviations from this criterion which his records show. Some of the more obvious causes, such as differences in soils, sunshine, temperature, etc., will be easy to identify; others will be more difficult but should nevertheless be carefully looked for in the growth history of the crop concerned.

An opportunity to make a study of this nature has been found in a recent summary of all Grade A "Amounts-of-Nitrogen" experiments which have been reported to us from the 1937 to 1942 crops inclusive. We have records from 396 such tests, conducted with different cane varieties under widely different soil and climatic conditions from north Kauai to south Hawaii. From each one of these tests we have selected the data which are associated with that specific nitrogen treatment which produced the optimum sugar yield (as averaged from not less than seven replicates in each experiment), *i.e.*, that level or amount of nitrogen which produced the maximum proved response in tons of sugar per acre. Thus we have basic data which can be considered as examples of a large number of very creditable field yields, *i.e.*, creditable for the specific areas and conditions involved. Unfortunately, in 271 of these experiments there was no proved increase in sugar yield for any amount of nitrogen greater than the minimum treatment used, so, for the purpose of this study, this minimum has had to be considered also as the optimum; this fact should be remembered in any analysis of the nitrogen efficiency values which are discussed hereafter.

*Plant Crops vs. Ratoons:*

One of the more commonly asked questions is that of the relationships between plant crops and ratoons. We have summarized some of these in Table I, and note several things which stand out therein. For instance, the plant crops were fully two months older than the ratoons and this may partly account for the fact that they have produced more cane and sugar per acre. Then, although it is indicated that both plant crops and ratoons have made their optimum sugar yields on the same average applications of nitrogen per acre (147 pounds), it is evident that the plant crops were more efficient users of their applied nitrogen and required it at the rate of one pound less per month. It can be assumed, however, that the plant crops received more nitrogen than the ratoons from the soil's natural nitrogen supplies.

TABLE I
PLANT VS. RATOON CROPS

| | | | Pounds of nitrogen | | Yields | | | | Pounds of nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crops | No. of tests | Age at harvest (mos.) | Per acre | Per month | TCA | TCAM | TSA | TSAM | Per ton cane | Per ton sugar | TC/TS |
| Plant | 119 | 21.4 | 147 | 7.0 | 87.0 | 4.1 | 9.5 | .45 | 1.8 | 16.1 | 9.2 |
| Ratoons* | 277 | 19.1 | 147 | 8.0 | 63.3 | 3.4 | 6.7 | .36 | 2.5 | 23.9 | 9.4 |

* Only 8 per cent older than third ratoons.

The plant crops produced almost one-tenth of a ton of sugar per acre per month more than the ratoons, and their optimum yields were made with greater nitrogen efficiency since less than two pounds of nitrogen were needed per ton of cane grown, whereas the ratoons for their optimum sugar yield required two and a half pounds of nitrogen per ton of cane. A similar relationship is seen for nitrogen efficiency expressed in terms of pounds of nitrogen per ton of sugar.

It is doubtful that the differences in tons cane per ton sugar (TC/TS) are significant, although we might expect the increased age of the plant crops to account for a slightly better quality.

*Season of Start:*

It is impossible in a study from the data which were available to separate the effects of the season of starting the crops from the season of harvest. However, the data in Table II have been summarized for study and interpretation by the individual reader who has his own ideas of this effect.

We believe there is some foundation in these figures for some of the opinions that we have long held with regard to optimum starting seasons. Thus both the fall- and winter-started crops, which got underway slowly in the cooler soil temperatures during these seasons, never quite made up in their yields for their slower start and, on an equivalent time basis, they made cane and sugar at slightly lower rates per month than crops which were started in the spring and summer.

Apparently these fall-started crops also needed more of the applied nitrogen than crops started earlier. This could be due to their slower "closing in" and a subsequently longer period of competition with weeds for the nitrogen which is supplied. Or it could be because of reduced supplies of natural soil nitrogen when the microorganisms in the cooler soil during this season become less active.

TABLE II

SEASON OF STARTING CROPS

| Season | No. of tests | Avg. age (mos.) | TSA | TSAM | TCAM | Pounds of nitrogen: Per acre | Per month | Per ton cane | Per ton sugar |
|---|---|---|---|---|---|---|---|---|---|
| Winter (Jan., Feb., Mar.) | 92 | 19.6 | 7.0 | .36 | 3.5 | 138 | 7.1 | 2.2 | 21.3 |
| Spring (Apr., May, June) | 118 | 20.7 | 8.1 | .39 | 3.6 | 147 | 7.3 | 2.1 | 19.8 |
| Summer (July, Aug., Sept.) | 121 | 19.7 | 8.1 | .41 | 3.8 | 155 | 8.1 | 2.3 | 21.5 |
| Fall (Oct., Nov., Dec.) | 65 | 18.4 | 6.4 | .36 | 3.4 | 146 | 8.4 | 2.6 | 25.5 |

*Pounds of Nitrogen per Acre:*

Although there is quite general agreement that a cane crop which is to be grown for only 15 or 16 months should actually need less nitrogen than one which will be nearer two years old at harvest, and that a 60-ton crop cannot efficiently use as much nitrogen as one which produces 100-ton cane, we still find a rather universal consideration of crop nitrogen needs on the basis of pounds per acre. Thus Table III has been prepared to show the relationships that are associated with those different amounts of nitrogen applied per acre that gave the optimum sugar yields in the experiments studied. The data are organized separately for both the plant and the ratoon crops.

TABLE III

POUNDS NITROGEN PER ACRE

| | Nitrogen applied lbs./acre | No. of tests | TCA | TSA | Age (mos.) | TCAM | TSAM | Pounds of nitrogen: Per month | Per ton cane | Per ton sugar |
|---|---|---|---|---|---|---|---|---|---|---|
| Plant Crops: | 100 or less | 29 | 77.0 | 7.9 | 20.2 | 3.9 | .39 | 4.6 | 1.2 | 12.0 |
| | 101–125 lbs. | 16 | 79.8 | 8.6 | 21.9 | 3.6 | .39 | 5.7 | 1.7 | 15.3 |
| | 126–150 lbs. | 29 | 91.8 | 9.8 | 21.6 | 4.4 | .46 | 7.0 | 1.7 | 16.2 |
| | 151–175 lbs. | 20 | 95.8 | 10.8 | 21.9 | 4.4 | .50 | 7.7 | 1.8 | 16.2 |
| | 176–200 lbs. | 10 | 87.7 | 10.4 | 21.1 | 4.2 | .50 | 9.5 | 2.3 | 19.4 |
| | Over 200 lbs.* | 15 | 92.5 | 10.7 | 22.2 | 4.2 | .49 | 10.6 | 2.6 | 22.6 |
| Ratoons: | 100 or less | 54 | 57.2 | 5.4 | 18.2 | 3.2 | .30 | 4.8 | 1.7 | 18.2 |
| | 101–125 lbs. | 46 | 61.1 | 6.5 | 19.0 | 3.3 | .35 | 6.6 | 2.1 | 20.5 |
| | 126–150 lbs. | 78 | 61.7 | 6.4 | 18.5 | 3.5 | .36 | 8.5 | 2.6 | 25.8 |
| | 151–175 lbs. | 43 | 68.4 | 7.4 | 19.6 | 3.6 | .38 | 8.9 | 2.6 | 25.6 |
| | 176–200 lbs. | 34 | 67.4 | 8.1 | 20.8 | 3.3 | .39 | 9.6 | 3.1 | 27.0 |
| | Over 200 lbs.† | 24 | 71.9 | 8.2 | 19.4 | 3.7 | .42 | 12.0 | 3.4 | 31.2 |

* Average 233 pounds. † Average 230 pounds.

For plant crops there appears to have been no advantage for nitrogen applications greater than 150 to 175 pounds per acre, for a crop harvested at about 22 months. The higher rates per acre are clearly responsible for increased nitrogen expenditures per month, per ton of cane, and per ton of sugar. For ratoons, however, even though they were harvested at perhaps two months younger, there are indications* that the per-acre application of nitrogen might be somewhat higher than

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* We use the word "indications" advisedly here because in eight of the 24 ratoon crops which received over 200 pounds N per acre, the actual amount used was the minimum amount included in the experiment concerned.

175 pounds per acre, for even though the two larger per-acre applications resulted in the use of larger amounts per month and per ton of cane and sugar, they were not proved inefficient in view of their beneficial effect on the sugar yields.

*Season of Harvest (See Table IV):*

Crops that were harvested during the summer season have given lower yields of cane and sugar, and have made cane and sugar at slower rates per month than crops taken off at other times. Fall-harvested crops have made cane at a slightly higher rate per month but these have given relatively poorer sugar yields than winter- or spring-harvested crops because of poorer quality; this may be partly due to their younger age at harvest but it is not unlikely that the influence of sucker growth, which is prevalent in fall-harvested cane, is also a contributory factor. Spring harvesting, because of its better cane quality, is undoubtedly the most desirable.

Efficient nitrogen utilization has not been significantly different except for nitrogen per month for the fall-harvested crops, and this may be because many short ratoons are included in this group.

TABLE IV

SEASON OF HARVEST

| | | | | | | | | Pounds of nitrogen | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | No. of tests | TCA | TSA | TC/TS | Age (mos.) | TCAM | TSAM | Per acre | Per month | Per ton cane | Per ton sugar |
| Winter (Jan., Feb., Mar.) | 93 | 77.1 | 8.3 | 9.3 | 20.3 | 3.8 | .41 | 155 | 7.7 | 2.2 | 19.9 |
| Spring (Apr., May, June) | 111 | 73.1 | 8.2 | 8.8 | 20.3 | 3.6 | .41 | 152 | 7.6 | 2.3 | 21.1 |
| Summer (July, Aug., Sept.) | 128 | 63.7 | 6.7 | 9.4 | 19.9 | 3.2 | .34 | 139 | 7.3 | 2.4 | 23.1 |
| Fall (Oct., Nov., Dec.) | 64 | 73.0 | 6.9 | 10.5 | 17.8 | 4.1 | .39 | 146 | 8.4 | 2.1 | 21.9 |

*Age at Harvest:*

In the four groups which are summarized in Table V, the influence of the age of the crop at harvest is definitely seen in the increases of both TCA and TSA, and in the improved juice quality (TC/TS).

Monthly nitrogen utilization appears to be high for the youngest age group, but this could be due to the fact that its actual minimum requirements were somewhat less than the plan of its specific tests was able to identify. However, there does appear to be a trend towards a lower monthly utilization of nitrogen as the crop age is increased. Again, except for this youngest age group, there is little difference between the other three groups in their nitrogen utilization per ton of cane or sugar. This similarity may indicate that total nitrogen applications which are based on a well-estimated cane tonnage, which in turn is also influenced by its expected age at harvest, should prove to be efficient and quite reliable; and the actual figure would not appear to be far from two pounds of nitrogen for each ton of cane.

## TABLE V

### AGE AT HARVEST

| Age group | No. of tests | TCA | TSA | Pounds of nitrogen Per acre | Pounds of nitrogen Per month | Pounds of nitrogen Per ton cane | Pounds of nitrogen Per ton sugar | TC/TS |
|---|---|---|---|---|---|---|---|---|
| Under 15 months.. | 38 | 52.0 | 5.2 | 149 | 11.1 | 3.03 | 30.2 | 10.0 |
| 15 to 18 months... | 130 | 64.0 | 6.5 | 133 | 7.9 | 2.20 | 21.8 | 9.8 |
| 19 to 22 months... | 137 | 74.3 | 8.1 | 152 | 7.3 | 2.16 | 20.5 | 9.2 |
| Over 22 months... | 91 | 81.6 | 9.3 | 158 | 6.5 | 2.10 | 19.3 | 8.8 |

*Cane and Sugar Yields:*

A breakdown of the average yields which were secured from the optimum treatment, that was indicated in each Grade A experiment included in this study, is given in Table VI. The eight groupings of TCA and the seven groups of TSA figures which are presented show certain interesting relationships: (1) An excellent positive and almost linear relationship is shown between the cane and the sugar yields; (2) both groups show their higher yields to be associated more directly with plant crops than with ratoons and, conversely, their lower yields to have come largely from ratoons; (3) increased yields were positively associated with increases in the age of the crops at harvest; and (4) positive correlations exist between the actual yields and the monthly rates at which both cane and sugar were produced.

With one exception (the 7.0–7.9 TSA group) the nitrogen efficiency values follow a definite pattern. Thus we find an increased use of nitrogen per acre, but a decreased utilization of nitrogen, both per ton of cane and of sugar, to be associated with the increases in yields of cane and sugar. About the only figure which does not materially change with each successive increase in the yield is that for pounds of nitrogen per month; this stays pretty close to 7.5 and only in the one exception noted does it go above 8.0.

## TABLE VI

### CANE AND SUGAR YIELDS

| Tons cane/acre | TSA | Number of Plant crops | Number of Ratoons | Age (mos.) | TCAM | TSAM | Pounds of nitrogen Per acre | Pounds of nitrogen Per ton cane | Pounds of nitrogen Per ton sugar | Pounds of nitrogen Per month |
|---|---|---|---|---|---|---|---|---|---|---|
| Under 40 ..... | 3.4 | 1 | 18 | 17.1 | 2.1 | .20 | 127 | 3.9 | 42.3 | 7.7 |
| 40–49 ........ | 4.8 | 4 | 41 | 17.4 | 2.7 | .28 | 133 | 2.9 | 28.9 | 7.9 |
| 50–59 ........ | 6.2 | 5 | 61 | 18.3 | 3.1 | .34 | 140 | 2.6 | 24.2 | 7.9 |
| 60–69 ........ | 7.1 | 14 | 60 | 19.7 | 3.4 | .36 | 143 | 2.2 | 21.3 | 7.5 |
| 70–79 ........ | 8.2 | 21 | 55 | 20.1 | 3.8 | .41 | 155 | 2.1 | 19.0 | 7.8 |
| 80–89 ........ | 9.3 | 25 | 25 | 20.8 | 4.2 | .45 | 156 | 1.9 | 17.2 | 7.6 |
| 90–99 ........ | 10.1 | 18 | 11 | 22.5 | 4.2 | .45 | 163 | 1.7 | 16.6 | 7.3 |
| Over 99 ...... | 12.3 | 31 | 6 | 22.4 | 5.1 | .55 | 158 | 1.4 | 13.0 | 7.1 |
| Tons sugar/acre | TCA | | | | | | | | | |
| Under 5.0 .... | 46.0 | 2 | 56 | 17.5 | 2.6 | .24 | 131 | 3.2 | 35.4 | 7.8 |
| 5.0–5.9 ....... | 59.2 | 5 | 54 | 18.5 | 3.2 | .31 | 134 | 2.4 | 24.3 | 7.5 |
| 6.0–6.9 ....... | 65.1 | 13 | 52 | 18.6 | 3.5 | .36 | 133 | 2.2 | 20.7 | 7.4 |
| 7.0–7.9 ....... | 72.1 | 13 | 44 | 19.5 | 3.7 | .39 | 157 | 2.3 | 21.2 | 8.3 |
| 8.0–8.9 ....... | 78.2 | 20 | 29 | 20.6 | 3.8 | .42 | 148 | 1.9 | 17.5 | 7.4 |
| 9.0–9.9 ....... | 86.1 | 18 | 20 | 21.0 | 4.1 | .46 | 153 | 1.9 | 16.3 | 7.5 |
| Over 9.9 ...... | 100.3 | 47 | 23 | 22.8 | 4.4 | .53 | 172 | 1.8 | 14.6 | 7.6 |

### *Tons of Sugar per Acre per Month:*

Because the age at which cane crops are harvested has such an important effect upon the yields, we have become accustomed to making many comparisons on the basis of sugar per acre per month. So for our next table (No. VII) we have arranged our data separately from plant crops and ratoons to show the relationships associated with specific TSAM groupings.

Since the optimum sugar yields recorded from 396 experiments are represented in Table VII, we should find some important associated nitrogen relationships therein. We do find that the 35 plant crops which made sugar at more than .50 TSAM used efficiently therefor an average of 173 pounds of nitrogen per acre, and produced an average of 107.4 tons of cane per acre in a period of 20.9 months. These excellent performances give us nitrogen efficiency values of 8.3 pounds of nitrogen per month, of 1.7 pounds of nitrogen per ton of cane, and of 14.6 pounds of nitrogen per ton of sugar.

At the same time, the 26 ratoon crops which performed better than .50 TSAM did so on practically the same amount of nitrogen per acre as the plant crops, *i.e.*, 175 pounds, but they were two months younger at harvest and made only 83.7 tons of cane per acre. Thus the nitrogen efficiency values for these ratoons were somewhat higher, *viz.*, 9.6 pounds per month, 2.1 pounds per ton of cane, and 17.4 pounds per ton of sugar. It is of interest that 13 of these 26 crops were short ratoons averaging in actual age only 15½ months, and their average production was .56 TSAM.

TABLE VII

TONS SUGAR PER ACRE PER MONTH (TSAM)

| | | | | | Pounds of nitrogen | | | |
|---|---|---|---|---|---|---|---|---|
| | TSAM | No. of tests | TCA | Age (mos.) | Per acre | Per month | Per ton cane | Per ton sugar |
| Plant Crops: | Under .25 ..... | 3 | 69.0 | 25.1 | 133 | 5.3 | 2.1 | 25.5 |
| | .25–.29 ........ | 6 | 63.4 | 22.3 | 143 | 6.2 | 2.2 | 22.8 |
| | .30–.34 ........ | 12 | 71.8 | 24.3 | 135 | 5.6 | 2.0 | 16.8 |
| | .35–.39 ........ | 17 | 74.8 | 21.4 | 117 | 5.6 | 1.6 | 15.2 |
| | .40–.44 ........ | 24 | 80.3 | 20.1 | 132 | 6.6 | 1.7 | 15.7 |
| | .45–.50 ........ | 22 | 88.5 | 21.3 | 156 | 7.5 | 1.8 | 15.8 |
| | Over .50* ...... | 35 | 107.4 | 20.9 | 173 | 8.3 | 1.7 | 14.6 |
| Ratoons: | Under .25 ..... | 40 | 47.2 | 20.9 | 134 | 6.5 | 3.1 | 35.6 |
| | .25–.29 ........ | 44 | 54.9 | 20.0 | 137 | 7.1 | 2.6 | 26.6 |
| | .30–.34 ........ | 40 | 58.5 | 18.1 | 135 | 7.6 | 2.4 | 24.2 |
| | .35–.39 ........ | 50 | 67.0 | 19.0 | 147 | 7.9 | 2.3 | 21.3 |
| | .40–.44 ........ | 43 | 69.9 | 18.6 | 152 | 8.4 | 2.2 | 20.0 |
| | .45–.50 ........ | 34 | 69.8 | 17.8 | 164 | 9.5 | 2.4 | 20.4 |
| | Over .50† ...... | 26 | 83.7 | 18.8 | 175 | 9.6 | 2.1 | 17.4 |

* Average .58. † Average .55.

### *Pounds of Nitrogen per Month:*

There have been occasional discussions among plantation agriculturists about the value of a figure for pounds of nitrogen per acre per month of growing time to be allowed, which might be used in estimating total crop nitrogen requirements, and subconsciously this idea has generally influenced decisions of amounts per acre to be applied. Specifically, however, it is doubtful whether this figure has heretofore been determined with sufficient accuracy to make its use dependable.

In Table VIII our data have been arranged to show various relationships with "pounds of nitrogen per month." There is little to indicate that the returns have significantly improved where each acre received nitrogen at a rate of more than eight pounds per month. Although it appears that a slightly better performance in terms of TSAM was obtained, and from a younger and smaller cane crop too, when this rate was more than 10 pounds per month, we cannot place too much reliance upon this interpretation because in 22 of the 63 experiments concerned, this high figure comes from the minimum amount of nitrogen which was not actually proved to be the optimum; without these 22 tests the average TSAM figure associated with "more than 9.9 pounds N/mo." (actually an average of 12.2 pounds per month) becomes only .40. However, there may be an interaction here with the age of the crop at harvest which has not been identified and which needs further study.

TABLE VIII
POUNDS OF NITROGEN PER MONTH

| Nitrogen applied: Pounds per month | No. of tests | TCA | TSA | Avg. age (mos.) | TCAM | TSAM | Average pounds nitrogen Per acre | Per ton cane | Per ton sugar |
|---|---|---|---|---|---|---|---|---|---|
| Less than 5.0* | 59 | 68.8 | 6.6 | 21.5 | 3.2 | .31 | 88 | 1.4 | 14.4 |
| 5.0 to 5.9 | 47 | 68.6 | 7.0 | 20.8 | 3.3 | .34 | 113 | 1.8 | 18.2 |
| 6.0 to 6.9 | 65 | 73.5 | 7.8 | 21.0 | 3.5 | .36 | 137 | 2.1 | 20.3 |
| 7.0 to 7.9 | 54 | 72.9 | 7.9 | 19.7 | 3.7 | .40 | 147 | 2.2 | 19.6 |
| 8.0 to 8.9 | 63 | 74.9 | 7.8 | 19.7 | 3.8 | .40 | 166 | 2.4 | 22.4 |
| 9.0 to 9.9 | 45 | 72.6 | 7.9 | 19.1 | 3.8 | .42 | 180 | 2.6 | 24.9 |
| More than 9.9† | 63 | 66.4 | 7.1 | 16.6 | 4.0 | .43 | 197 | 3.2 | 30.7 |

* Average 4.1. † Average 12.1.

*Pounds of Nitrogen per Ton of Cane:*

Still another measurement that has been considered for guidance in the total nitrogen allowance for a cane crop is one that is based upon the expected cane tonnage that will be produced. From their previous experience, fieldmen are able to make fairly reliable estimates of what their cane yields should be. Hence if we could set a reliable figure for nitrogen requirements on the basis of pounds of nitrogen per ton of cane, we should not stray very far from efficiency in its use.

In Table IX the data which are presented indicate that the better performances have come from those crops which received nitrogen at the lower levels per ton of cane harvested; in fact, the average results from applications of less than two pounds of nitrogen per ton of cane have been quite good. Evidently other growth factors than nitrogen were responsible for the poorer yield performance and the greater expenditures of nitrogen per acre, per month, or per ton of sugar. Hence attempts to increase sugar yields by supplying nitrogen at amounts much higher than two pounds per ton of cane are not likely to be successful.

TABLE IX
POUNDS OF NITROGEN PER TON OF CANE

| Nitrogen applied: Pounds per ton cane | No. of tests | TCA | TSA | Age (mos.) | TCAM | TSAM | Average pounds nitrogen Per acre | Per month | Per ton sugar |
|---|---|---|---|---|---|---|---|---|---|
| Less than 1.5* | 68 | 91.5 | 9.3 | 20.8 | 4.4 | .44 | 104 | 5.0 | 11.5 |
| 1.5 to 1.9 | 93 | 78.8 | 8.0 | 20.2 | 3.9 | .40 | 132 | 6.7 | 16.9 |
| 2.0 to 2.4 | 102 | 71.3 | 7.7 | 19.8 | 3.6 | 39 | 153 | 7.9 | 20.5 |
| 2.5 to 2.9 | 65 | 63.7 | 6.9 | 19.3 | 3.3 | .37 | 163 | 8.7 | 24.7 |
| 3.0 to 3.4 | 32 | 58.5 | 6.4 | 19.5 | 3.0 | .33 | 180 | 9.4 | 29.6 |
| More than 3.4 | 36 | 48.9 | 5.0 | 18.1 | 2.7 | .29 | 195 | 11.4 | 43.0 |

* Average 1.2.

## *Summary:*

In attempting to build up a background of experience and to find certain criteria which can be used to judge relative performances and efficiency in sugar cane agriculture, we have studied the records from the optimum treatment of a large number of field experiments. From these tests certain crop relationships have been identified, and the more important of these may be summarized as follows:

1. Plant crops produced higher yields than ratoons.

2. Plant crops made more efficient use of applied nitrogen fertilizers.

3. Crops started in October, November, and December produced poorer yields and were less efficient in their use of nitrogen.

4. Nitrogen supplied at 150 to 175 pounds per acre was adequate for plant crops and at this rate was efficiently used. For ratoons, slightly larger per acre amounts were indicated.

5. Harvesting from January to June was indicated as most desirable; July to September harvests gave disappointingly low yields.

6. Improved juice quality and higher yields of cane and sugar followed from increases in the age at harvest.

7. An almost linear relation was found between the cane and the sugar yields.

8. A higher nitrogen requirement per acre, but less per ton of cane and sugar, was associated with increases in yields, but nitrogen-per-month values were quite constant regardless of changes in yields.

9. Nitrogen efficiency values from those crops which had the best performance records (as TSAM) were as follows:

| Crops | lbs. N/acre | lbs. N/month | lbs. N/ton cane | lbs. N/ton sugar |
|---|---|---|---|---|
| Plant .................. | 173 | 8.3 | 1.7 | 14.6 |
| Ratoons ................ | 175 | 9.6 | 2.1 | 17.4 |

10. The highest nitrogen efficiency values are actually indicated as being about eight pounds per month, and at about two pounds per ton of cane.

# Rat-trapping Records Show Effectiveness of Control Methods

By R. E. Doty

*Data from trapping records over a period of five years are presented as a basis of evaluating the efficiency of the prebaited feeding-station method of rat control in sugar cane fields of Hawaii.*

*These data show the high degree of efficiency that can be attained by systematic and continuous rat-control measures.*

The object of this study was to obtain information on the efficiency of the prebaited feeding-station method of rat control by the use of systematic trapping following the regular prebaiting and poisoning rounds.

It was also desirable to determine the relative densities of the rat population through the different seasons of the year, as well as the density that will probably continue to be maintained even under systematic and effective prebaiting and poisoning practices which result in very little rat-damaged cane at harvest.

This method of rat control has been adequately described by the writer in *The Hawaiian Planters' Record*, 42: 39–76, 1938. Briefly, it makes use of portable, covered feeding stations which are placed at strategic points and baited with loose unpoisoned grain for from five to six days to establish confidence in focal points of good feeding grounds for the rats in the vicinity. When rat suspicion of this new food supply has been overcome and the take of bait indicates considerable activity, a quick change to a bait which is similar in all respects except that a poison has been added will result in a good acceptance of the poisoned grain before the rats suspect that it has been changed.

Following each round of poison, approximately once in every three months, an index of the remaining rat population was secured by setting out ordinary spring traps baited with chunks of coconut.

The work was carried on at the Kauai Variety Station in 18.2 acres of cane land, which is a part of Field 19 Hanamaulu, of The Lihue Plantation Company, Ltd. This area is adjacent to the county road and in the heart of a large area of cane land. A small side branch of Wailua gulch extends up into one side of the area, thus exposing the Variety Station's cane to rat reinfestation from a large area of wasteland.

Prior to the prebait control program which began in August 1938, this area was heavily infested with rats and damage to cane crops was extremely serious, being especially severe along the field edges next to the wasteland. Trapping, torpedo poisoning, and experimental prebaiting were carried on during the latter half of 1937 and the first half of 1938. These control measures were not entirely satisfactory as this small area of cane was almost immediately reinfested with rats.

Lihue Plantation began prebaiting work on a small scale in January 1938. In August 1938 a cooperative arrangement was inaugurated between Lihue Plantation and Kauai Variety Station by which the plantation would prebait and poison the Variety Station area at the same time as their entire surrounding cane area. In return the station staff would trap and record the catch of rats from 100 traps per day, spaced over the 18.2 acres, during the period between the prebaiting rounds.

We now have an almost continuous trapping record for 100 traps per day in this 18.2 acres of cane for a period of five years and five months (August 25, 1938, to January 25, 1944), and it is the purpose of this report to bring together all data relating to this study and to make such compilations, graphs, and comments as seem to be warranted.

## RAT POPULATION AT KAUAI VARIETY STATION BEFORE SYSTEMATIC PREBAITING AND POISONING BECAME ROUTINE PRACTICE

H. K. Stender reported in at least two of his monthly reports (August and September 1938) that before the first Lihue Plantation prebaiting, August 1938, trapping work yielded around eight rats per 100 traps per day. The records of intermittent trapping of rats at the Variety Station during the months of April to August 1938 inclusive, while various control measures were being tried, show the following interesting figures:

### TABLE I

### TRAPPING RECORDS BEFORE PREBAITING

| Year and month | Average rats caught per 100-trap days |
|---|---|
| 1938: | |
| April | 5.2 |
| May | 6.4 |
| June | 6.9 |
| July | 5.8 |
| August | 9.7 |
| Total | 34.0 |
| Average | 6.8 |

Comments in reports by Mr. Stender* during this period indicated that cane damage was continuing.

## RAT POPULATION AT KAUAI VARIETY STATION DURING THE PERIOD OF SYSTEMATIC PREBAITING—AUGUST 25, 1938, TO JANUARY 25, 1944

The records of rats trapped during this period have been tabulated and summarized. Table II gives the detailed data by months, with yearly totals showing: (1) number of days 100 traps were set; (2) total rats caught; and (3) average number of rats per 100 traps per day. Table III shows the average number of rats caught per 100 traps per day, by months with the five-year average.

By plotting the average number of rats caught per 100 traps for the months from April to August 1938 inclusive (previous to systematic prebaiting), and comparing this curve with other curves secured by plotting* the rat catch for the corresponding months during the next three years (1939, 1940, 1941) following the start of prebaiting, we have a clear picture which shows a marked reduction in the number of rats caught. These curves are presented in Fig. 1. All commercial cane damage by rats ceased somewhere between the extremes shown in Fig. 1.

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* **Monthly Reports from the Kauai Variety Station.**

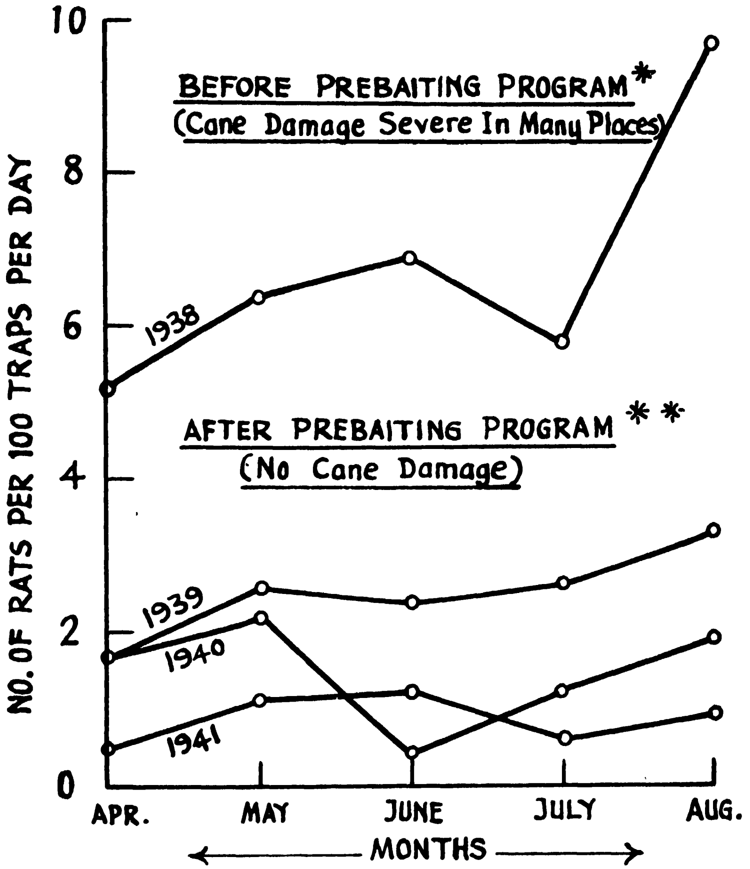

Fig. 1. Graphic presentation of the average number of rats caught per 100 traps per day, comparing the period April to August 1938, just previous to systematic prebaiting, with that of the corresponding months of the years 1939, 1940, 1941 under a systematic prebaiting program. * From Table I. ** From Table III.

The average number of rats caught per 100 traps per day each year (last line in reinfestation prevents any appreciable reduction by the present control methods. An Table III) has been plotted in Fig. 2 and shows a marked reduction in the rat population index from 1938 to 1939 and 1940, followed by only slight fluctuations from 1940 to date. Apparently a low point in the rat population has been reached where almost total absence of rat-eaten cane stalks is evidence that the present schedules of prebaiting and poisoning rounds are giving very satisfactory control.

It is highly probable that any further reduction in the rat population within the cane areas can be attained only at a much higher cost. However, it is feasible to move control equipment and personnel into the waste edges from which this continuous reinfestation is emanating and create an effective barrier of rat-free waste country immediately adjacent to the cane. In waste areas where rats are very abundant, Kaeleku Sugar Company, Ltd., is effectively fighting them by maintaining permanent feeding and poisoning stations along "buffer" trails which have been cut in the forest or wasteland 200 to 300 feet from, and running roughly parallel to, the cane field borders.

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* From Table III.

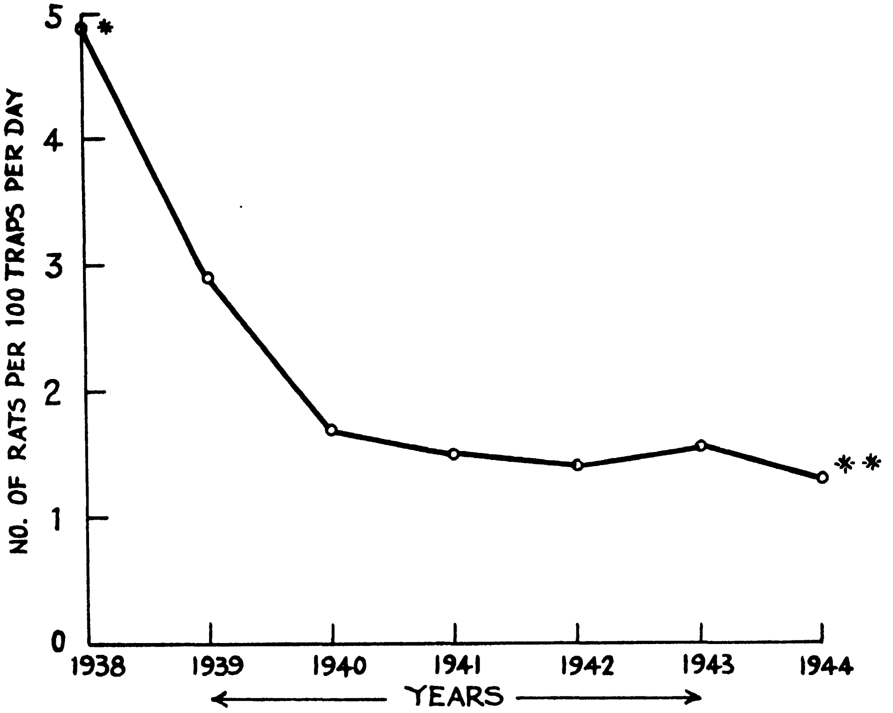

Fig. 2. Average number of rats caught per 100 traps per day under prebaiting control by The Lihue Plantation Company (averages by years for the period from August 27, 1938, to January 25, 1944). * September to December inclusive. ** January only.

## TABLE II

## RATS CAUGHT PER 100 TRAPS PER DAY WITHIN 18.2 ACRES OF CANE LAND OF THE KAUAI VARIETY STATION (COMPILED FROM DETAILED RECORDS MADE BY MR. STENDER)

| Year and month | No. of days 100 traps set | Total rats trapped | No. of rats per 100 traps per day |
|---|---|---|---|
| 1938: | | | |
| September | 29 | 88 | 3.0 |
| October | 19 | 73 | 3.8 |
| November | 21 | 126 | 6.0 |
| December | 29 | 185 | 6.4 |
| Totals and avg. | 98 | 472 | 4.82 |
| 1939: | | | |
| January | 31 | 106 | 3.4 |
| February | 16 | 58 | 3.6 |
| March | 31 | 110 | 3.6 |
| April | 31 | 54 | 1.7 |
| May | 22 | 57 | 2.6 |
| June | 31 | 75 | 2.4 |
| July | 30 | 78 | 2.6 |
| August | 17 | 56 | 3.3 |
| September | 31 | 36 | 1.2 |
| October | 30 | 87 | 2.9 |
| November | 20 | 64 | 3.2 |
| December | 30 | 112 | 3.7 |
| Totals and avg. | 320 | 893 | 2.79 |
| 1940: | | | |
| January | 31 | 120 | 3.9 |
| February | .. | .. | ... |
| March | 25 | 15 | 0.6 |
| April | 31 | 54 | 1.7 |
| May | 15 | 33 | 2.2 |
| June | 28 | 10 | 0.4 |
| July | 30 | 35 | 1.2 |
| August | 21 | 39 | 1.9 |
| September | 31 | 41 | 1.3 |
| October | 30 | 45 | 1.5 |
| November | 21 | 53 | 2.5 |
| December | 29 | 52 | 1.8 |
| Totals and avg. | 292 | 497 | 1.70 |
| 1941: | | | |
| January | 31 | 98 | 3.2 |
| February | 31 | 50 | 1.6 |
| March | 16 | 16 | 1.0 |
| April | 31 | 14 | 0.5 |
| May | 30 | 33 | 1.1 |
| June | 29 | 36 | 1.2 |
| July | 14 | 8 | 0.6 |
| August | 31 | 27 | 0.9 |
| September | 17 | 18 | 1.1 |
| October | 30 | 28 | 0.9 |
| November | 31 | 52 | 1.7 |
| December | 30 | 95 | 3.2 |
| Totals and avg. | 321 | 475 | 1.48 |
| 1942: | | | |
| January | 22 | 64 | 2.9 |
| February | 31 | 89 | 2.9 |
| March | 28 | 81 | 2.9 |
| April | 15 | 11 | 0.7 |
| May | 21 | 22 | 1.0 |
| June | 31 | 26 | 0.8 |
| July | 16 | 9 | 0.6 |
| August | 31 | 28 | 0.9 |
| September | 31 | 17 | 0.5 |
| October | 30 | 31 | 1.0 |
| November | 31 | 13 | 0.4 |
| December | 30 | 57 | 1.9 |
| Totals and avg. | 317 | 448 | 1.41 |
| 1943: | | | |
| January | 31 | 42 | 1.4 |
| February | 31 | 81 | 2.6 |
| March | 15 | 16 | 1.0 |
| April | 31 | 6 | 0.2 |
| May | 30 | 31 | 1.0 |
| June | 31 | 39 | 1.3 |
| July | 18 | 17 | 0.9 |
| August | 30 | 38 | 1.3 |
| September | 31 | 83 | 2.7 |
| October | 20 | 23 | 1.2 |
| November | 28 | 50 | 1.8 |
| December | 30 | 79 | 2.6 |
| Totals and avg. | 326 | 505 | 1.55 |
| 1944: | | | |
| January | 31 | 40 | 1.3 |

## TABLE III

## AVERAGE NUMBER OF RATS CAUGHT PER 100 TRAPS PER DAY BY MONTHS, FROM SEPTEMBER 1938 TO JANUARY 1944 INCLUSIVE

| Months | Rats per 100 traps (year) | | | | | | | 5-year period 1939–1943 | |
|---|---|---|---|---|---|---|---|---|---|
| | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | Total | Monthly average |
| January | ... | 3.4 | 3.9 | 3.2 | 2.9 | 1.4 | (1.3) | 14.8 | 3.0 |
| February | ... | 3.6 | ... | 1.6 | 2.9 | 2.6 | ... | 10.7 | 2.7 |
| March | ... | 3.6 | 0.6 | 1.0 | 2.9 | 1.0 | ... | 9.1 | 1.8 |
| April | ... | 1.7 | 1.7 | 0.5 | 0.7 | 0.2 | ... | 4.8 | 1.0 |
| May | ... | 2.6 | 2.2 | 1.1 | 1.0 | 1.0 | ... | 7.9 | 1.6 |
| June | ... | 2.4 | 0.4 | 1.2 | 0.8 | 1.3 | ... | 6.1 | 1.2 |
| July | ... | 2.6 | 1.2 | 0.6 | 0.6 | 0.9 | ... | 5.9 | 1.2 |
| August | ... | 3.3 | 1.9 | 0.9 | 0.9 | 1.3 | ... | 8.3 | 1.7 |
| September | 3.0 | 1.2 | 1.3 | 1.1 | 0.5 | 2.7 | ... | 6.8 | 1.4 |
| October | 3.8 | 2.9 | 1.5 | 0.9 | 1.0 | 1.2 | ... | 7.5 | 1.5 |
| November | 6.0 | 3.2 | 2.5 | 1.7 | 0.4 | 1.8 | ... | 9.6 | 1.9 |
| December | 6.4 | 3.7 | 1.8 | 3.2 | 1.9 | 2.6 | ... | 13.2 | 2.6 |
| Yearly average | 4.82 | 2.79 | 1.70 | 1.48 | 1.41 | 1.55 | ... | | |

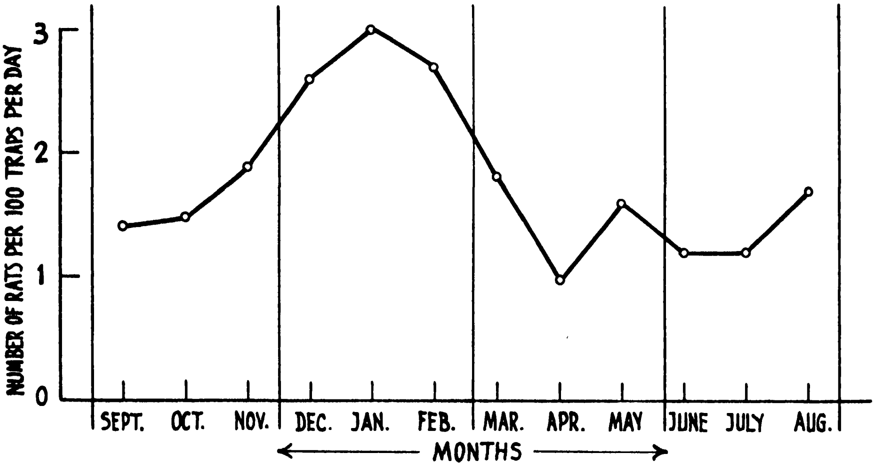

**Fig. 3.** Average number of rats caught per 100 traps per day under prebaiting control by The Lihue Plantation Company. Five-year average by months—1939–1943 (from Table III, last column).

## SEASONAL FLUCTUATION IN RAT POPULATION

The seasonal fluctuation of the rat population, in cane fields under the prebaited feeding-station control, is shown in the last column of Table III. This table gives the average number of rats caught per 100 traps per day by months for the five-year period under study. These figures are plotted on the graph in Fig. 3. It is noteworthy that the total range of this seasonal fluctuation in rat population was from a low of one rat per 100 traps per day for April to a high of only three in January. Apparently even three rats per 100 traps per day is very satisfactory, since very little, if any, rat-damaged cane could be found during January.

The period from August or September to January inclusive is a period of increasing rat migration into the cane, which reaches a peak during January of each year and then declines again to a low level occurring from April to August. Thus these conclusions made from the above data agree with previous observations reported by many fieldmen. Incidently, the period of high pregnancy in rats (April to September inclusive) shown in Spencer's* tabulation coincides rather closely with this period of low migration. Perhaps this fact indicates a tendency of the adult rats to stay in the wasteland where permanent cover is abundant while they are busy at nest building and caring for their young. Then as the young rats grow up and shift for themselves, they migrate to new locations, including cane lands where food may be more abundant, and where if left undisturbed many will establish permanent homes.

## A STUDY OF THE CHANGE IN THE RAT POPULATION WITH ELAPSED TIME FOLLOWING A PREBAITING AND POISONING ROUND

The purpose of this study was to detect any increase in the rat population that was the direct result of the elapsed time between one prebait and poison round and the next. For this purpose Table IV was compiled from the detailed trapping records by weeks between each prebait and poison round for the period from August 27, 1938, to January 25, 1944. The average number of rats caught per 100 traps per day during the total trapping period during each succeeding week after poisoning is shown. The table covers 13 weeks in detail with the 14th, 15th, and 16th week combined because of the small number of records. The periods of poisoning were tabulated first by groups of three months each beginning with: (1) Septem-

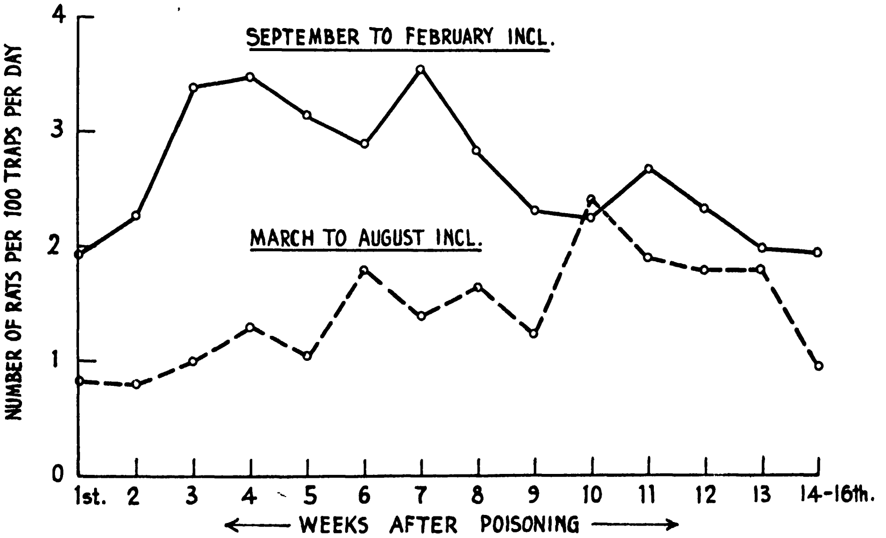

Fig. 4. Average number of rats caught per 100 traps per day during each succeeding week following prebaiting and poisoning campaigns (from Table IV).

The solid line shows the rats caught per 100 traps per day following prebaiting and poisoning done during September to February inclusive.

The broken line shows the rats caught per 100 traps per day following prebaiting and poisoning done during March to August inclusive.

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* Garlough, F. E., Spencer, H. J. and Jordan, W., 1937. Hawaiian Rat Project. Semiannual Report (Jan. 1 to June 30, 1937) of the Bureau of Biological Survey. Division of Game Management, Control Methods Research Laboratory, p. 12.

ber, October, and November; (2) December, January, and February; (3) March, April, and May; and (4) June, July, and August. These figures were then combined into six-month periods for comparison. By this arrangement the first two groups covering the period from September to February, which carried the highest averages, were placed together. The graph in Fig. 4 has been prepared from the six-month averages, September to February and March to August inclusive.

It is quite evident that there has been very little change in the rat population within the Variety Station area during the three-month periods between the prebaiting and poisoning rounds. The prebait control work has been so efficient in this area that only very low rat populations have been available for this special study. This has prevented us from securing spectacular figures on the amount of reinfestation of rats with elapsed time after a poison round. Under the conditions of this test, it is evident that there is no permanent resident population at the Kauai Variety Station; the rats which have been caught are transients coming from other areas, especially the wasteland in the adjacent gulch.

TABLE IV

AVERAGE NUMBER OF RATS TRAPPED PER 100 TRAPS PER DAY FOR EACH WEEK FOLLOWING EACH ROUND OF PREBAITING AND POISONING BETWEEN AUGUST 27, 1938, AND JANUARY 25, 1944

| Weeks following each poisoning round | Months of poisoning | | | | | | |
|---|---|---|---|---|---|---|---|
| | September October November | December January February | True average September to February | March April May | June July August | True average March to August | True average September to August |
| 1...... | 1.76 | 2.64 | 1.95 | 0.79 | 0.86 | 0.83 | 1.36 |
| 2...... | 2.04 | 3.07 | 2.27 | 0.74 | 0.86 | 0.81 | 1.46 |
| 3...... | 3.47 | 3.07 | 3.38 | 0.71 | 1.24 | 1.00 | 2.07 |
| 4...... | 3.37 | 3.79 | 3.46 | 1.49 | 1.10 | 1.27 | 2.24 |
| 5...... | 3.43 | 2.07 | 3.13 | 0.89 | 1.17 | 1.04 | 1.98 |
| 6...... | 2.98 | 2.57 | 2.89 | 1.60 | 1.90 | 1.77 | 2.27 |
| 7...... | 3.62 | 3.29 | 3.54 | 1.26 | 1.52 | 1.40 | 2.35 |
| 8...... | 2.48 | 3.86 | 2.82 | 1.83 | 1.48 | 1.64 | 2.14 |
| 9...... | 2.43 | 1.79 | 2.27 | 1.17 | 1.26 | 1.22 | 1.67 |
| 10...... | 2.14 | 2.36 | 2.20 | 2.50 | 2.31 | 2.40 | 2.31 |
| 11...... | 2.88 | 1.90 | 2.69 | 1.68 | 2.06 | 1.88 | 2.26 |
| 12...... | 2.66 | 0.59 | 2.31 | 0.79 | 2.26 | 1.76 | 2.04 |
| 13...... | 2.23 | 0.87 | 1.98 | 0.75 | 2.64 | 1.77 | 1.90 |
| 14–15–16...... | 1.93 | .... | 1.93 | 0.90 | 1.00 | 0.94 | 1.51 |
| Average...... | 2.70 | 2.60 | 2.68 | 1.27 | 1.48 | 1.38 | 1.98 |

The present schedule of rounds is considered very satisfactory, since the population has been kept at a low level, with no cane damage reported. The variation in the rat population has been influenced more by the season of the year in which they were caught than by the elapsed time since a poisoning round had been completed. This would explain the slight decline of the September to February curve after seven weeks (see Fig. 4) since the rat population declined and remained low under prebaiting from April to July without any reference to time elapsed after a poison round (see Fig. 3).

## SEASON OF YEAR WHEN MOST OF THE POISONING WORK WAS DONE

It is interesting to note that out of 19 poison rounds covering a period of five years and five months, only two were carried out during December, January, and February, while seven were finished during September, October, and November. During the December to February period the weather is likely to be unfavorable for prebait and poison work. Experience has also shown that extra effort should be put into the field rat-control work beginning with September in order to offset the natural increase in the rat populations which is due to young rats maturing at this time.

## SUMMARY AND CONCLUSIONS

1. A study of the effect of prebaiting and poisoning on the rat population at the Kauai Variety Station was made from August 27, 1938, to January 25, 1944.

2. Before the systematic prebaiting was inaugurated, the field rat population yielded an average catch of 6.8 rats per 100 traps per day for the months of April to August 1938.

3. The corresponding months of the following years (1939–1943 inclusive) under the prebaiting system of control showed that a very satisfactory reduction in the rat population had been maintained as follows:

| | Year | Number of rats caught per 100-trap days for the months of April to August |
|---|---|---|
| Before prebaiting | 1938 | 6.8 |
| After prebaiting* | 1939 | 2.52 |
| After prebaiting | 1940 | 1.48 |
| After prebaiting | 1941 | 0.86 |
| After prebaiting | 1942 | 0.80 |
| After prebaiting | 1943 | 0.94 |

* Averages from April to August figures in Table III.

4. The yearly averages (12 months) of the rats caught per 100-trap days since prebaiting was started are as follows:

| Year | Rats per 100-trap days |
|---|---|
| 1938 (Sept. to Dec. only) | 4.82 |
| 1939 | 2.79 |
| 1940 | 1.70 |
| 1941 | 1.48 |
| 1942 | 1.41 |
| 1943 | 1.55 |

5. There has been no appreciable rat damage to cane since prebaiting and poisoning by the feeding-station method was started.

6. A study of the seasonal fluctuations of the rat population in the cane field under prebaiting shows that the amount of reinfestation from outside areas begins to rise in October of each year, reaches a peak in December and January, and then declines to April of the year following. From April to July migration to the cane land is at the lowest ebb of the entire year.

7. A study of the change in rat population with elapsed time following a pre-

baiting and poisoning round shows that no significant or damaging increase took place during the interval (averaging 3½ months) between poisoning rounds. The usual seasonal variation in migration to cane land from outside areas was greater than this increase due to the length of time between poisonings.

## ACKNOWLEDGEMENT

We wish to express our appreciation for the fine cooperation between the staff of The Lihue Plantation Company, particularly Masato Kawamura, and Mr. Stender and Yuki Inouye of the Kauai Variety Station which has made this study possible.

# Susceptibility of Exchangeable Potassium in Hawaiian Soils to Loss by Leaching*

By A. S. Ayres

*A study is reported of the effect of intensive leaching on the potassium status of four Hawaiian soils differing widely in available (exchangeable) potassium content. The degrees of potassium saturation of the soils in relation to the losses of potassium, the effect of leaching upon the levels of potassium, and the source of the leached potassium are discussed.*

Conditions obtaining in the soils of substantial areas in Hawaii are conducive to loss of potassium by leaching. This loss may be a result of excessive rainfall or of unevenly distributed irrigation water. The susceptibility of soil potassium to leaching under such conditions is largely dependent upon the tenacity with which exchangeable potassium is held by the soil. Little of a quantitative nature is known, however, regarding the abilities of Hawaiian soils to retain exchangeable potassium against the leaching action of water, or of the factors governing such abilities.

Soil-solution potassium, which is small in amount compared with the exchangeable form, is free to move with any movement of the water in which it is dissolved and is therefore highly susceptible to leaching. Exchangeable potassium, on the other hand, is not subject to leaching as such but, under certain conditions, may be readily brought into the soil-solution, or leachable form. This conversion takes place whenever the concentration of potassium in the soil solution is decreased below the level at which the two forms of potassium are in equilibrium. Part of this conversion is normally brought about by carbonic acid resulting from the respiration processes of plants and soil microorganisms. To a greater extent, perhaps, particularly in the absence of vegetation, the release of potassium is accomplished by hydrolysis. The mechanism of this release may be represented by the following equation, where the letter "X" represents the negatively charged colloids comprising the exchange material of the soil and "KX" the exchangeable potassium in combination with this material:

$$KX + H_2O = HX + K^+ + OH^-$$

It will be seen that hydrogen derived from the water replaces potassium in the exchange material thus rendering the potassium free to move with any downward movement of the soil water.

McGeorge (9) determined, in a laboratory study, the losses of potassium which resulted when a number of soils, chiefly from the island of Hawaii, were leached with distilled water. A similar study of two soils from Olaa (Hawaii) was made

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*** Published by permission of the Director of the Hawaii Agricultural Experiment Station as Technical Paper No. 116. Most of the experimental work was conducted while Dr. L. A. Dean was head of the Department of Chemistry and Soils. The writer is indebted to Dr. Dean for helpful advice and criticism.**

recently by Van Brocklin (12). The latter employed distilled water impregnated with sufficient carbon dioxide to simulate rain water. With all of the soils examined by these workers, the leachates contained substantial amounts of potassium even after several successive additions of water had been made to the soils, suggesting that part of the leached potassium was derived from the exchangeable fraction. Magistad (8) reported in a lysimeter study, annual losses of only 15 pounds $K_2O$ per acre resulting from rainfall of 58 inches, and of 28 pounds resulting from 92 inches of rainfall, from two uncropped Oahu soils which had never received fertilizer. In this case it is apparent that losses of exchangeable potassium by leaching were very slight. Fireman and Bodman (5), in California, found that severe leaching with distilled water (1,920 inches) lowered the level of exchangeable potassium in an Aiken clay loam from 1.19 milliequivalents per 100 grams of soil to from 0.26 to 0.54 milliequivalent, depending upon the depth of the soil in the column. The more moderate leaching (65.7 inches) of a Yolo clay loam containing 0.84 milliequivalent of potassium resulted, however, in an almost negligible reduction in the level of potassium. Correspondingly small losses of exchangeable potassium by leaching from calcareous Arizona soils have been reported by McGeorge (10). It is apparent from the foregoing review that widely differing results have been obtained relative to the susceptibility of exchangeable potassium to leaching.

The writer (2), in a study of the abilities of Hawaiian soils to take up potassium from solution, found that with soils containing only moderate levels of exchangeable potassium, sorption occurred even when the concentration of potassium did not exceed a few parts per million $K_2O$. Soils containing very high levels of exchangeable potassium, however, did not take up potassium until the concentration in the solution was in excess of about 25 p.p.m. It seemed logical to assume that, if a soil is unable to take up potassium from a solution of this concentration, the soil will, if water is substituted for the solution, tend to establish in the water a substantial concentration of potassium. In such soils a portion of the exchangeable potassium would therefore be expected to be very susceptible to leaching.

## EXPERIMENTAL

The soils initially selected for the study were a high-potassium sugar cane field soil from Aiea (Oahu), a high-potassium soil from a papaya orchard at Kailua (Oahu), and a virgin Manoa (Oahu) soil which was only moderately supplied with potassium. All of these soils were essentially clay soils. The levels of exchangeable potassium in the soils, together with certain other properties pertinent to the study, are shown in Table I.

Following air drying, a four-pound portion of each soil was placed in a large glass tube, forming a column of soil about one foot in depth. Sufficient distilled water was added to each soil to raise the moisture content to maximum field capacity. Additional water, equivalent to five inches, was then applied to each soil; the resulting leachates were collected and analyzed for potassium. This process was repeated until a total of 520 inches of water had been applied to each soil, except that after the soils had been leached with about 50 inches of water, the five-inch increments of leachate were no longer analyzed individually, several being combined and analyzed as a unit.

After 145 inches of water had passed through each soil, the soil column, divided into three roughly equal sections, was air dried and analyzed for exchangeable potassium. This was done in order to determine the uniformity of the level of potassium remaining in the column. Following the analysis, the three sections of the soil were returned to their respective positions in the tube and leaching was resumed. At the conclusion of the experiment the columns of soils were, with the exception of the Manoa soil, again sectioned and analyzed.

As the effects of leaching became apparent, it was decided to include in the study a soil representative of the high-rainfall soils of the Hilo coast (Hawaii). Accordingly, leaching was commenced on a sample of soil which had been in the laboratory for some time and which reputedly had been obtained from the Hilo Variety Station of the Experiment Station, H.S.P.A. However, as a result of the determination of certain chemical characteristics of the soil, some doubt was cast upon the origin of the specimen. The sample is, therefore, not accepted as being representative of the area in question and the anonymity is reflected by reference to the soil throughout the paper as soil "A." The soil is very high in exchangeable potassium, as may be seen by reference to Table I. The treatment received by soil "A" was the same as that received by the other soils except that it was leached with only 355 inches of water and was not removed from the tube for analysis until the conclusion of the experiment.

## METHODS OF ANALYSIS

Exchangeable potassium was extracted from the soils with normal ammonium acetate adjusted to pH 6.8. Twenty-five-gram samples were shaken mechanically for an hour with 250 ml. of the solution. After standing overnight the solution was filtered off under suction and an additional 250 ml. allowed to percolate slowly through the soil. Potassium in the leachates was determined by the method of Volk and Truog (13).

Base-exchange capacities were measured by the barium-hydroxide method of

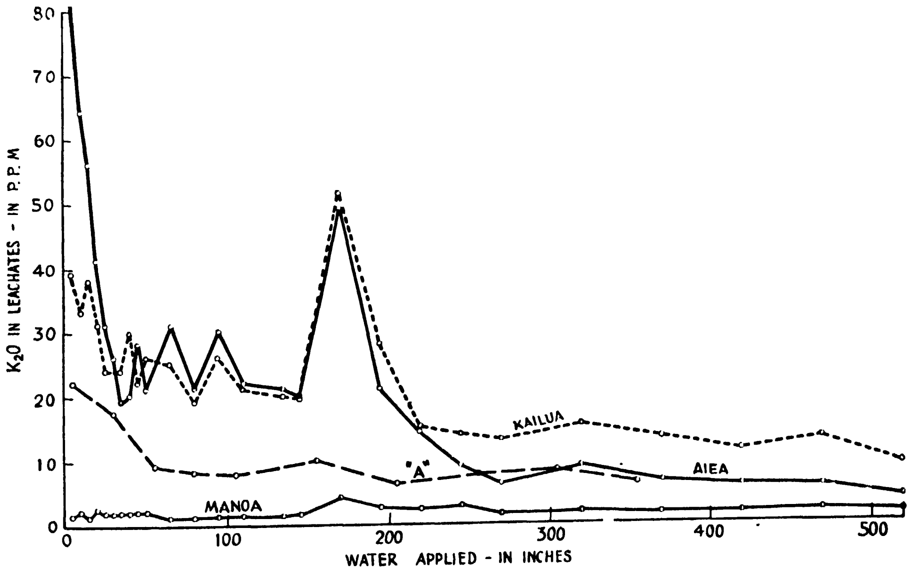

Fig. 1. Potassium in leachates.

Parker (11). The pH values of the ammonium-soils prepared during the procedure ranged from 7.4 to 8.0.

Determinations of pH were made on soil pastes, employing the glass electrode.

## Potassium in Leachates

In Fig. 1 the levels of potassium in the leachates are plotted against the amounts of water with which the soils were leached. The level of potassium in the leachate from the moderately supplied Manoa soil did not vary consistently during the early stages of the experiment. Levels of potassium in the leachates from the other three soils, however, were initially high—from approximately 22. to 82. p.p.m. $K_2O$—but dropped rapidly and irregularly during the early stages of leaching.

The sharp and pronounced increases in the potassium contents of the Aiea and Kailua leachates, and the moderate rise in the Manoa leachate at 145 inches, arose from the air drying of the soils at this point. In the case of soil "A," which was kept moist throughout the experiment, there was no corresponding increase in the concentration of potassium in the leachate.

After the influence of air drying had subsided, the Aiea and Kailua leachates decreased gradually in potassium content until the end of the experiment, at which time the $K_2O$ values were, respectively, 4 and 9 p.p.m. The level of potassium in the leachate from the Manoa soil appears to have been little affected by the leaching; values varied from about 1.5 to 2.0 p.p.m. throughout the experiment, except for a short period immediately following air drying. The leachate from soil "A" dropped only slightly in potassium content following the initial decrease already referred to.

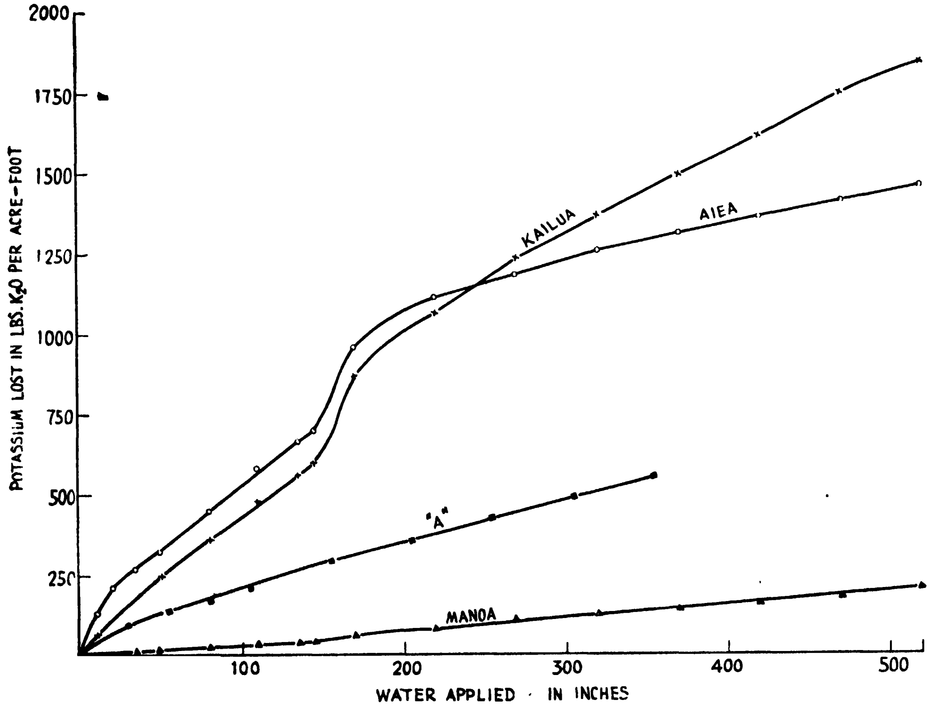

Fig. 2. Losses of potassium by leaching as determined by analysis of leachates.

## LOSSES OF POTASSIUM BY LEACHING

### *Effect of the Decreasing Level of Exchangeable Potassium:*

Curves showing the losses of potassium, based upon analysis of the leachates, are shown in Fig. 2. The unusual shapes of the curves representing the Manoa, Aiea and Kailua soils between 145 and a little over 200 inches resulted from the air drying of the soils.

An inspection of the Aiea and Kailua curves indicates that as leaching progressed the slopes of the curves diminished. This may be seen, in spite of the distortion mentioned, by comparing the slopes prior to drying with the slopes after the influence of the drying had ceased to be manifest. There appears to be only a very slight decrease in the slope of the curve for soil "A." It seems probable that, had this soil been as intensively leached as the others, a more pronounced effect might have been noted. In the case of the Manoa soil no diminution in slope with leaching is observable.

The results appear to indicate that as the amounts of exchangeable potassium in soils abundantly supplied with this nutrient are reduced, the susceptibility of the remaining potassium to loss by leaching is likewise reduced. It seems not unlikely that the same principle may apply to soils at any level of potassium, although at low levels it may be of little or no practical importance, as suggested by the essentially linear nature of the curve for the Manoa soil.

### *Influence of the Degree of Potassium Saturation:*

It is apparent from Fig. 2 that the Manoa soil, which contained the least amount of exchangeable potassium initially (Table I), suffered the least loss of potassium. This observation suggests a relationship between the leachability of potassium and the level of exchangeable potassium in the soil. Upon this basis, however, it would be expected that the Aiea soil, which is second to the Manoa soil in potassium content, would have lost second to the least amount of potassium. Such, however, is not the case. It is thus apparent that, although the susceptibility of potassium to leaching in a *particular soil* may be related to the level of exchangeable potassium in that soil (as seen in the preceding section), the relationship does not appear to hold where different soils are concerned.

Attention may be turned at this point to a consideration of the losses of potassium suffered by the soils in light of the degree or extent to which each soil is saturated with potassium. The "degree of potassium saturation" expresses the quantity of exchangeable potassium in a soil in relation to the base-exchange capacity. It is usually expressed upon a percentage basis. The degrees to which the soils employed in this study were initially saturated with potassium are indicated in Table I.

Reference to Table I and to Fig. 2 will show that the Manoa soil, which lost the least amount of potassium (205 pounds $K_2O$ per acre-foot of soil), possessed also the lowest degree of potassium saturation, or 2.3 per cent. Soil "A," which lost much more potassium than the Manoa soil, possessed a degree of potassium saturation of 5.0 per cent, or a little more than double that of the Manoa soil. Similarly, the Aiea soil, with a degree of saturation of 7.3 per cent, sustained a greater loss of potassium than soil "A," and the Kailua soil, with the highest degree of saturation (8.4 per cent), suffered the greatest loss of potassium, or 1,845 pounds $K_2O$.

## TABLE I

## EXCHANGEABLE POTASSIUM CONTENTS OF THE SOILS AT VARIOUS STAGES OF LEACHING, AND INITIAL AND FINAL pH VALUES

| Description | Rainfall | Section of soil column | Base-exchange capacity | Initial degree of potassium saturation | pH | | Exchangeable Potassium | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Initial | Final | Initially | Remaining after 145 inches | | Remaining after 355 inches | | Remaining after 520 inches | |
| | *inches* | | *m.e./100 gm.* | *per cent* | | | *m.e./100 gm.* | *m.e./100 gm.* | *per cent* | *m.e./100 gm.* | *per cent* | *m.e./100 gm.* | *per cent* |
| Manoa, residual virgin soil | 165 | top | 24.0 | 2.3 | 5.2 | ... | .56 | .49 | 87.5 | .... | .... | .... | .... |
| | | middle | 24.0 | 2.3 | 5.2 | ... | .56 | .55 | 98.2 | .... | .... | .... | .... |
| | | bottom | 24.0 | 2.3 | 5.2 | ... | .56 | .56 | 100.0 | .... | .... | .... | .... |
| | | mean | .... | ... | ... | 5.2[2] | .... | .... | 95.2[1] | .... | .... | .45[2] | 80.3[2] |
| Aiea, residual sugar cane field soil | 45 | top | 17.9 | 7.3 | 5.7 | 5.2 | 1.30 | .53 | 40.8 | .... | .... | .31 | 23.8 |
| | | middle | 17.9 | 7.3 | 5.7 | 5.4 | 1.30 | .76 | 58.5 | .... | .... | .39 | 30.0 |
| | | bottom | 17.9 | 7.3 | 5.7 | 5.5 | 1.30 | .82 | 63.1 | .... | .... | .45 | 34.6 |
| | | mean[1] | .... | ... | ... | ... | .... | .... | 54.1 | .... | .... | .... | 29.5 |
| Kailua, alluvial papaya orchard soil—formerly in pasture | 50 | top | 28.9 | 8.4 | 6.2 | 5.6 | 2.43 | 1.58 | 65.0 | .... | .... | .69 | 28.4 |
| | | middle | 28.9 | 8.4 | 6.2 | 5.7 | 2.43 | 2.01 | 82.7 | .... | .... | .91 | 37.4 |
| | | bottom | 28.9 | 8.4 | 6.2 | 5.8 | 2.43 | 2.35 | 96.7 | .... | .... | 1.15 | 47.3 |
| | | mean[1] | .... | ... | ... | ... | .... | .... | 81.5 | .... | .... | .... | 37.7 |
| "A" | .. | top | 39.1 | 5.0 | 6.5 | 6.1 | 1.95 | .... | .... | 1.35 | 69.2 | .... | .... |
| | | middle | 39.1 | 5.0 | 6.5 | 6.1 | 1.95 | .... | .... | 1.60 | 82.0 | .... | .... |
| | | bottom | 39.1 | 5.0 | 6.5 | 6.1 | 1.95 | .... | .... | 1.62 | 83.1 | .... | .... |
| | | mean[1] | .... | ... | ... | ... | .... | .... | .... | .... | 78.1 | .... | .... |

[1] These values only approximate the true averages since the weights of the sections were not identical.

[2] The Manoa soil was not sectioned at the conclusion of the experiment.

The degrees of potassium saturation in the soils studied thus appear to account nicely for the losses of potassium sustained by the soils at the conclusion of the experiment. But they fail to explain why potassium was lost more rapidly from the Aiea soil than from the Kailua soil during the first half of the experiment. It may be pointed out, however, that the losses during this period did not differ greatly for the two soils, nor was the initial difference in the degrees of potassium saturation very great. Moreover, it will be noted that with the widening in the gap between the degrees of saturation, as a result of the more rapid loss of potassium from the Aiea soil during the first half of the experiment, a point was reached at which the rate of loss from the Aiea soil was exceeded by that from the Kailua soil.

It is not supposed that the degree of potassium saturation is the entire answer to the susceptibility of potassium to leaching. It seems evident, however, from a consideration of the present results, that the degree of potassium saturation offers a more satisfactory indication of the susceptibility of potassium to leaching than does the mere level of exchangeable potassium in the soil.

It may prove reassuring to recall that in a recent study of high-rainfall soils by the writer (3), high base-exchange capacities were generally found to prevail. Since the levels of exchangeable potassium in these soils were only moderate, the degrees of potassium saturation were on the whole very low—in many instances even lower than in the Manoa soil employed in the present study. This suggests that losses of potassium by leaching in regions of high rainfall may not be so great as might be anticipated.

## INFLUENCE OF LEACHING ON THE pH AND ON THE LEVELS OF EXCHANGEABLE POTASSIUM

### *pH Values:*

The replacement of exchangeable bases by hydrogen in soils results in increased acidity. Since such replacement occurs when soils are leached with water it would be anticipated that some evidence of increased acidity should have resulted from the determination of the pH values of the soils before and after leaching. Referring to Table I, it will be observed that marked increases in acidity resulted from leaching in three of the four soils. The Manoa soil, which was the most acid initially (pH 5.2), and which experienced the least loss of potassium, was not made measureably more acid by leaching.

### *Levels of Exchangeable Potassium:*

The effect of leaching upon the levels of exchangeable potassium in the soils is brought to light in Table I. Considering first the Manoa soil, it will be seen that leaching with 145 inches of water reduced the level of exchangeable potassium, for the soil as a whole, to 95.2 per cent of the original value. The passage of additional water through the soil further reduced the level of potassium so that at the end of the experiment only 80.3 per cent of the original amount remained. In the case of the Aiea soil the reduction was much more severe: at 145 inches the average level of potassium had dropped to 54.1 per cent of the amount initially present and, by the end of the experiment, to 29.5 per cent. The amounts of exchangeable potassium remaining in the Kailua and "A" soils upon completion of leaching were, respectively, 37.7 and 78.1 per cent of the original levels. The reductions in levels of exchangeable potassium in the Aiea and Kailua soils are comparable with those brought about by Fireman and Bodman (5) on Aiken clay loam.

It is evident from inspection of the levels of exchangeable potassium in the several sections of the soil columns that depletion of the soil was far from uniform. Levels of potassium following leaching are seen, in every instance, to increase with increasing depth in the column. Similar results were obtained in the study referred to just above. The simplest explanation of this differential loss of potassium appears to be that the water, as it moves downward through the soil, increases in potassium content and as a result its effectiveness as a leaching agent continually decreases. In view of the marked resistance of Hawaiian soils to dispersion, it seems unlikely that colloidal migration could account for the observed differential.

## SOURCE OF THE LEACHED POTASSIUM

If all of the potassium leached out of the soils was derived from the soil-solution and exchangeable forms, then it should be possible to account for this potassium on the basis of the quantities of exchangeable potassium* present in the soils, before and after leaching. The quantities of potassium lost from the soils, calculated upon the two bases, and taking into account the soil removed from the tubes for analysis during the course of the experiment, are shown in Table II in terms of pounds of $K_2O$ per acre-foot of soil.

TABLE II

LOSSES OF POTASSIUM BY THE SOILS AS A RESULT OF LEACHING

| Soil | Initial level of exch. potassium *lbs.* $K_2O$*/acre-ft.* | Final level of exch. potassium[3] *lbs.* $K_2O$*/acre-ft.* | Loss in exch. potassium by difference *lbs.* $K_2O$*/acre-ft.* | Loss in potassium by analysis of leachates *lbs.* $K_2O$*/acre-ft.* | Loss in potassium by analysis of leachates minus loss by difference *lbs.* $K_2O$*/acre-ft.* |
|---|---|---|---|---|---|
| Manoa[1] ....... | 665 | 535 | 130 | 205 | 75 |
| Aiea[1] ......... | 1,535 | 445 | 1,090 | 1,460 | 370 |
| Kailua[1] ....... | 2,865 | 1,075 | 1,790 | 1,845 | 55 |
| "A"[2] ........ | 2,300 | 1,795 | 505 | 550 | 45 |

[1] Leached with 520 inches of water.
[2] Leached with 355 inches of water.
[3] Weighted mean for the entire soil column.

In the case of every soil the amount of potassium lost, as determined by direct measurement, exceeded that lost, as measured by difference. With the Manoa, Kailua, and "A" soils, these differences were small—from 45 to 75 pounds $K_2O$—and may be without significance. There seems little question, however, that in the Aiea soil some form of potassium other than the soil-solution and exchangeable forms contributed to the observed leaching loss.

It may be contended that the method employed in the determination of potassium did not remove all of the exchangeable potassium from the soils. Although the possibility cannot be denied, the method employed (see Methods of Analysis) provides for an unusually thorough treatment. Moreover, had the potassium unaccounted for been the result of incomplete extraction in the determination of exchangeable potassium, differences of similar magnitude might have been expected with the other soils studied.

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* The laboratory determination of exchangeable potassium includes the soil-solution potassium.

During the last ten years it has been shown that in some mainland soils and under certain conditions considerable amounts of non-exchangeable potassium may be converted to exchangeable and soil-solution forms over a relatively short period of time. Similar conclusions have been drawn by Abel and Magistad (1) and by Borden (4) as a result of their efforts to evaluate available potassium in Hawaiian soils. In view of the results of these workers, it seems not unreasonable to suppose that that part of the potassium lost from the Aiea soil, which could not be accounted for on the basis of the diminution in exchangeable potassium, was converted from a non-exchangeable to the leachable form during the course of the experiment. The observation is of interest also in view of the studies of Hough and his associates (6, 7) which revealed the presence of considerable amounts of potassium in the colloidal fractions of some Hawaiian soils.

## SUMMARY

The results of a laboratory study of the effects of leaching upon the potassium status of four Hawaiian soils may be summarized as follows:

1. Air drying was found to increase the susceptibility of potassium to leaching.
2. In soils at high initial levels of exchangeable potassium, the susceptibility of potassium to leaching appears to diminish with decreasing level of potassium in the soil.
3. The degree of potassium saturation of a soil appears to be a more reliable guide to the susceptibility of potassium to leaching than does the level of exchangeable potassium. Losses of potassium were found to be greater, the higher the initial degrees of potassium saturation.
4. The quantities of potassium lost from the soils ranged from about 200 to 1,850 pounds $K_2O$ per acre-foot of soil.
5. The acidity of the soils was generally increased as a result of leaching.
6. Levels of exchangeable potassium were reduced by leaching to from about 30 to 80 per cent of the original values.
7. A substantial amount of potassium apparently from a non-exchangeable source was leached from one of the soils studied.

## LITERATURE CITED

(1) Abel, F. A. E., and Magistad, O. C., 1935. Conversion of soil potash from the nonreplaceable to the replaceable form. Jour. Amer. Soc. Agron. 27: 437–445.

(2) Ayres, A. S., 1941. Sorption of potassium and ammonium by Hawaiian soils. The Hawaiian Planters' Record, 45: 93–106.

(3) ——————, 1943. Soils of high-rainfall areas in the Hawaiian Islands. Hawaii Agr. Expt. Sta. Tech. Bul. No. 1, 41 pp.

(4) Borden, R. J., 1941. Potash requirements for sugar cane. The Hawaiian Planters' Record, 45: 131–146.

(5) Fireman, M., and Bodman, G. B., 1939. The effect of saline irrigation water upon the permeability and base status of soils. Soil Sci. Soc. of America Proc., 4: 71–77.

(6) Hough, G. J., and Byers, H. G., 1937. Chemical and physical studies of certain Hawaiian soil profiles. Tech. Bul. 584, U. S. D. A., 26 pp., illus.

(7) ——————, Gile, P. L., and Foster, Z. C., 1941. Rock weathering and soil profile development in the Hawaiian Islands. Tech. Bul. 752, U. S. D. A., 43 pp.

(8) Magistad, O. C., 1933. Pineapple News, Chemistry report, 7: 32–37.

(9) McGeorge, W. T., 1914. Absorption of fertilizer salts by Hawaiian soils. Hawaii Agr. Expt. Sta. Bul. 35, 32 pp.
(10) ————, 1933. Potassium in calcareous soils. Ariz. Agr. Expt. Sta. Tech. Bul. 50, 42 pp., illus.
(11) Parker, F. W., 1929. The determination of exchangeable hydrogen in soils. Jour. Amer. Soc. Agron., 21: 1030–1039.
(12) Van Brocklin, F. R., 1939. Report of committee in charge of the Expt. Sta., H. S. P. A., pp. 98–99.
(13) Volk, N. J., and Truog, E., 1934. A rapid chemical method for determining the readily available potash of soils. Jour. Amer. Soc. Agron., 26: 537–546.

# A Survey of Insect Pests of New Caledonia

By Francis X. Williams

*Many insect pests of plant crops are here considered. A large number of these pests do not occur in Hawaii. A short account of the island of New Caledonia and its natural history is included.*

In May 1940 the Experiment Station of the Hawaiian Sugar Planters' Association sent the writer to New Caledonia to collect and study the insect pests of that large island. Thus in securing a better knowledge of these pests we would be more fully prepared to prevent their entrance into this Territory or to deal immediately with any such that did perchance succeed in establishing themselves here. So rapid and extensive is the development of modern transportation, particularly by the airplane, that preventive measures not always having kept pace, the danger of accidental introduction of insects and other pests seems every day to become more real.

Sailing from Honolulu on May 27 and arriving at Noumea, capital of New Caledonia, on July 3 *via* a rather circuitous route, I spent over four months in entomological work in various parts of the island, and departed from it *via* Pan American Airways on November 12. The data secured are perhaps representative though quite incomplete, for to make a thorough survey of the insect pests of so large and rugged an island, the biota of which is sometimes affected by conditions of drought or flood, would be a matter of years rather than of months.

During my entire stay in New Caledonia I was the recipient of much kindness and assistance. I am much indebted to Professor Jean Verges, Director of Agriculture, who opened the way for my entomological investigations in the truck gardens of New Caledonia and who assisted me in other ways. Lee Johnson of Noumea kindly placed his vegetable and ornamental garden at my disposal for studying the insects associated with it. Thanks are due to the Marist fathers at their mission at St. Louis, a few miles from Noumea and where some native gardens were situated. Through the hospitality of Mr. and Mrs. L. Want at their ranch at Oua Tom on the west coast, I was able to observe pests of cotton and coffee. Robert Virot, an able botanist, helped in the identification of various plants, while the several field trips with him proved to be of great interest. I received much assistance in travel, both by sea and by land: to the Isle of Pines (Kunie) and way points (courtesy of Tibbie Hagen); to a lumber camp near Nepoui, just beyond Poya and about 150 miles up the west coast; to Hienghene some 170 miles up the east coast; and to other points. Albert Roger proved indispensable in his knowledge of people and places, in making arrangements relative to our trips, and by his reassuring operation of the automobile. Mrs. Williams, who accompanied me, took all the photographs in New Caledonia and otherwise helped me in my work. The photographs of mounted specimens were made by W. Twigg-Smith of this Experiment Station.

Past work in entomology in the Pacific Islands has been of great aid to me in the identification of insects, their economic status, distribution, etc. This is particularly true of the careful investigations in Guam and Samoa of O. H. Swezey, consulting entomologist of this Experiment Station. Mr. Swezey has personally helped me determine a number of insect species. D. T. Fullaway, entomologist of the Territorial Board of Agriculture and Forestry, has determined the aphids or plant lice, many of the scale insects, and nearly all the parasitic wasps in the New Caledonian collection. F. A. Bianchi, assistant entomologist of this Experiment Station, has studied the Thysanoptera or thrips and will soon publish on this important group of insects. C. E. Pemberton, executive entomologist at this Experiment Station, has brought together a list of some of the most important insect pests of New Caledonia, and this list has been found very useful. Finally a catalogue of insects known to occur in New Caledonia, kindly furnished the Experiment Station by E. C. Zimmerman, entomologist of the Bernice P. Bishop Museum, Honolulu, has helped a great deal.

Unfortunately I have not seen—except in review—Dr. Risbec's fine papers nor the excellent publications of others on New Caledonian insect pests.

The island of New Caledonia (Fig. 1) was discovered by Captain James Cook in 1774, and is a dependency of France. It has a northwest-southeast trend and lies between latitudes 20° 1′ and 22° and 26′ south and longitudes 164° and 167° 40′ east. It is about 750 nautical miles northeastward of Brisbane, Australia, somewhat less that distance southwestward of Fiji and about 3,300 miles southwestward of Honolulu, Hawaii. It is approximately 248 miles long with an average breadth of 25-30 miles and has an area of 6,274 square miles, or more than half again as

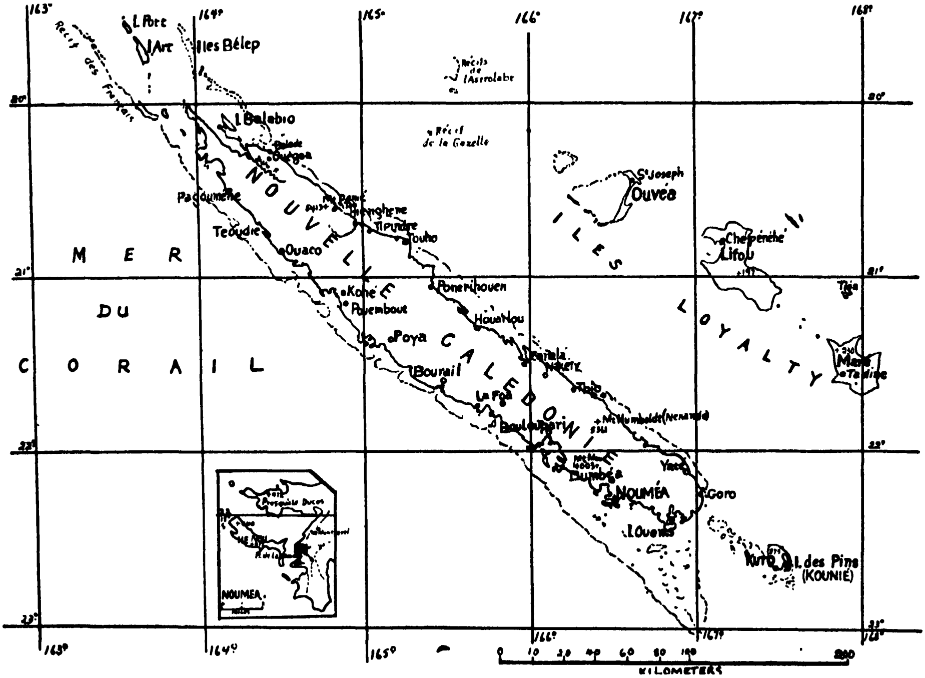

Fig. 1. Map of New Caledonia.

large as the island of Hawaii. Less than 30 miles beyond its southern extremity is the Isle of Pines (Kunie), area 58 square miles, while 50 miles or more off the east coast are the small Loyalty Islands. All of these islands and some others are under the jurisdiction of New Caledonia. Noumea, population about 12,000, is near the extremity of a small peninsula on the west coast near the southern end of the island. North and east of the main island of New Caledonia are the New Hebrides, the nearest island of which is over 200 miles distant.

New Caledonia is enclosed by coral reefs. The island is ruggedly mountainous, the highest points being Mount Panie in the north and Mount Humboldt in the south. Both are approximately 5,400 feet high. Some 20 miles northwest of Noumea is the square-topped Mount Mou, elevation about 4,000 feet, a familiar landmark from the city and its environs and somewhat recalling our Mount Kaala of Oahu in its broad, apparently level summit. Recent figures (prior to 1940) give the population of New Caledonia as about 53,000, of which the natives—chiefly Melanesians—constitute somewhat more than half, the whites nearly a third, with Japanese, indentured Javanese and Tonkinese making up the remainder.

New Caledonia is a very ancient land mass; there is much palaeozoic rock and no volcanic activity. In the north there is a fine gneiss mountain chain, which includes Mount Panie. Near Hienghene and standing out to sea from a scenic craggy coast are the "Tours de Notre Dame de Paris", a pair of towering rocks arising from a common base, of crystalline limestone. But the most familiar country consists of serpentine rock. To quote R. H. Compton (*Geographical Journal*, 90: 81-106, 1917, 12 photos, on page 85) "Owing to the great quantity of iron contained in the rocks the whole of the serpentine country has a very characteristic red ochre colour, . . ." In fact much of the surface rock is very heavy and strikes with a distinct metallic ring. But the lack of good coal has made this iron (haematite) comparatively useless. New Caledonia, however, is rich in workable minerals, with nickel, chrome, and cobalt outstanding. Nickel is shallowly mined by terracing the hill tops or cutting into the hill sides. This mineralized area constitutes a kind of plant zone, the vegetation being rather stunted on the impoverished soil.

The rainfall is fairly abundant over the island: "The average rainfall from 1908 to 1912 was 1845 mm (73 inches) per annum, distributed over 142 rainy days." (Compton, ibid :89–90.) It is not evenly distributed and some of the lower country is rather arid. The rainy season is from December to March—more or less. Occasionally there are cyclones, and the east-southeast trade winds are often vigorous. The climate is rather mildly tropical but it becomes slightly cooler at sea level than in the Hawaiian Islands. During almost our entire stay in New Caledonia, from July to November, the weather was almost ideal although not the best time of the year for insects.

The east coast is more rugged and generally wetter, the mountains sloping steeply towards the sea, their streams often debouching from narrow valleys. Roads are fewer and one usually crosses the estuaries by ferry barge. The west coast has some plains and is fringed here and there by mangrove swamps. Particularly on the west coast and frequently extending up the mountains to an altitude of 3,000 feet or more are large areas of open forest consisting almost entirely of "niaouli" (*Melaleuca leucadendron* Linn., variety *viridiflora* Gaernt.) of the

Myrtaceae or Eucalyptus family (Fig. 2). It is practically the same as the Australian *Melaleuca leucadendron* which has been introduced into Hawaii where it is commonly known as the paper bark. This picturesque if frequently rather scrubby and distorted tree with its shaggy, pale-brown bark and narrow dull-green leaves gives the New Caledonian landscape a rather hazy appearance that is far from tropical. The niaouli is a very hardy tree, withstanding wind and drought as well as considerable salt water. Grass will grow beneath its dubious shade so as to permit pasturage. Its flowers appearing seasonally in great profusion are said to be the mainstay of the honeybee. The medicinal "essence de niaouli" is made from the leaves, the layered papery bark is extensively used in the "bush" for thatching, the wood makes good charcoal, or when properly dried, excellent firewood, and suitably curved trunks or large limbs are sometimes employed in boat building. It is also used a great deal for fence posts.

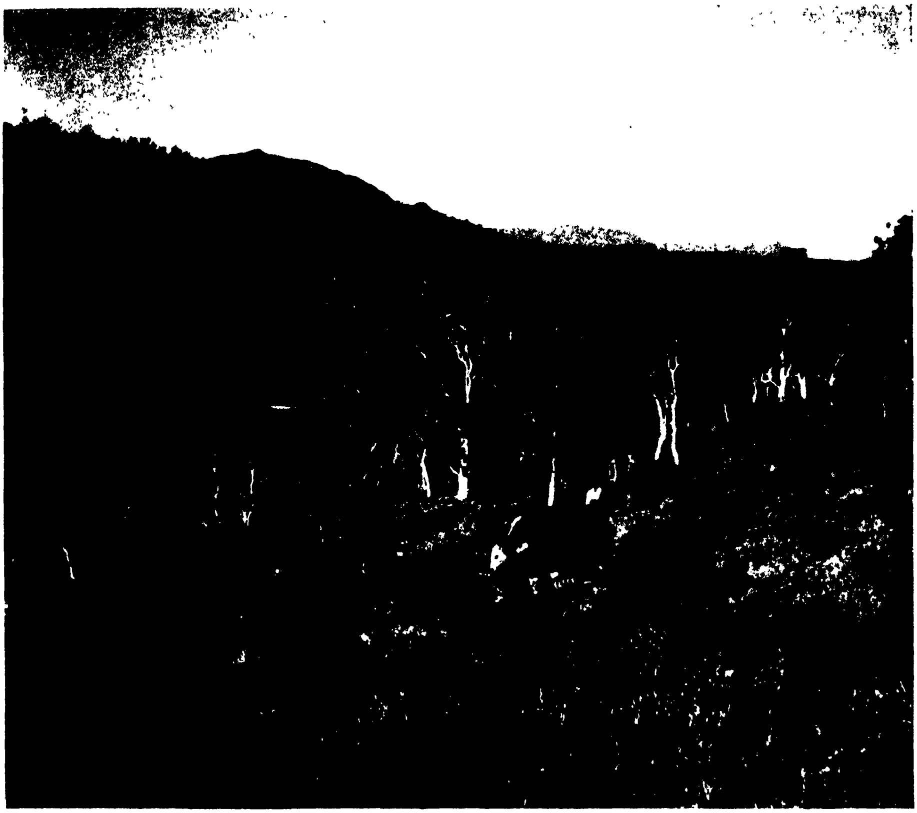

Fig. 2. "Niaouli" forest (*Melaleuca leucadendron* var. *viridiflora*).

Several species of wattle (*Acacia*) are found from sea level to well up in the mountains. The "haut forêt" or high forest is composed largely of endemic trees. Such forests are to be seen in pockets in the valleys and on the higher mountains where there is sufficient moisture. Here tree ferns may attain a height of 50 feet or more. *Blechnum* ferns and others add greatly to the beauty of forest streams. Palms are not conspicuous. These forests in many places have been badly cut and their future is not reassuring. Such fine trees as the several species of kauri pine (*Agathis*), that occur in little groups or colonies and perhaps the most stately of New Caledonia's forest giants, have already been greatly reduced in numbers, in part as export for matchwood. The less valuable but picturesque "pin colonnaire" (*Araucaria Cookii* R. Br. [=*A. columnaris* Hook.]) furnishes a cheaper type of lumber for many uses. One or more species of *Araucaria* often form part of the skyline of the mountains. To the south, *Araucaria Cookii* is frequently the outstanding tree of coral islets.

As in the Hawaiian Islands of old there was an extensive trade in sandalwood in New Caledonia.

As one enters the harbor of Noumea, the brown hills overlooking the city present a rather barren picture. In addition to the usually dry grass, there are introduced weeds and shrubs now common to many tropical countries. The ordinary bush lantana (*Lantana camara* Linn.) helps form thickets on the hillsides, but this plant or a variety of it with particularly attractive blossoms is often grown in gardens. The dainty little *Lantana sellowiana* Link and Otto seeds itself freely and forms patches of purple over the landscape. A tough verbenaceous weed (*Stachytarpheta*) is common, and these several plants together with the thorny *Acacia farnesiana* Willd., our "klu bush," often make walking along the overgrown trails difficult. The Christmas berry tree (*Schinus terebinthifolius* Raddi) and the lemon guava (*Psidium guajava* Linn.) flourish in New Caledonia as in Hawaii. One or more species of *Sida* are common city weeds. At least two kinds of prickly pear cactus are found about Noumea; the abundant one has the flattened branches not as fleshy as usual and the second species, of which I saw but few individuals, is a sturdier plant with larger thorns and which I was told had been very greatly reduced in numbers by the larva of the Argentine *Cactoblastis* moth that has so efficiently dealt with the prickly pear in Australia, from which country it was imported into New Caledonia.

Other plants more natural to the country may be seen in the hills back of Noumea. Waist-high thickets of dark green are formed by a dwarf ironwood (*Casuarina collina* Poisson?), while shrubs that closely resemble our *Dodonaea* and *Wikstroemia* are scattered on the slopes. In the gulches are remnants of forests of low trees.

While New Caledonia is rich in species of insects, vertebrate animals are poorly represented. Best known of the wild animals is an Indian stag deer sufficiently abundant to be a pest, so that many estates, particularly those engaged in raising cattle (the meat-canning industry being large) maintain a deer hunter. There is, consequently, quite an export trade in deer hides. Species of rat and pig occur and are sometimes considered as dating back from prehistoric times. Among the bats of New Caledonia are three species of flying foxes or large fruit-eating bats. Locally known as "roussetes," they are often prized as food and are said to descend periodically from their mountain fastnesses to feed upon the flowers of the niaouli tree. Town birds are represented by the mynah—not as assertive it would seem as in Hawaii; the house sparrow; fig-loving white-eyes; a honeysucker known as the longbec, a fine singer often seen probing hibiscus flowers; and a few other birds. Along the roads near the sea one often sees a partly green- and blue-marked little kingfisher (*Halcyon*) perched on the electric power wires. A crow and several hawks are common. Owl pellets—regurgitated wads of indigestible animal material—collected in the hills behind Noumea indicate that the food of this bird consists to a great extent of small rodents, large grasshoppers and crickets. No remains of birds were found in these pellets. One often finds bleached specimens of a large noctuid moth, perhaps of the genus *Anua* and whose caterpillar feeds upon the leaves of the niaouli, skewered on the strong thorns of the shrubby *Acacia farnesiana* (Fig. 3). This is probably the work of shrikes or butcher birds, which are numbered among the avifauna of the island. In the forests are the "kagu" (*Rhinochetus jubatus* Verreaux and Des Murs), a ground-inhabiting heron-like bird; the "notu" (*Phaenorhina goliath* Gray), which is a very large pigeon; a crow; some parakeets; and other interesting forms. There are apparently no land snakes but plenty of skink and gecko lizards; one species of gecko (*Rhacodactylus leachianus* [Cuv.]) dwelling on trees and in the fissures of rocks attains a length of more than a foot and is much feared by the natives. Large terrestrial snails (*Placostylus*), some with shells five inches long, occur on the ground near the shore or in the depth of the forest. They appear harmless to vegetation. These snails or "escargots" are often served in restaurants as delicacies, although not universally acclaimed as such. The common European snail (*Helix aspersa* Müll.) (Fig. 4) is an escape in gardens where it is a great pest. The mother of pearl and the troca shells from the sea have been much used in the manufacture of buttons.

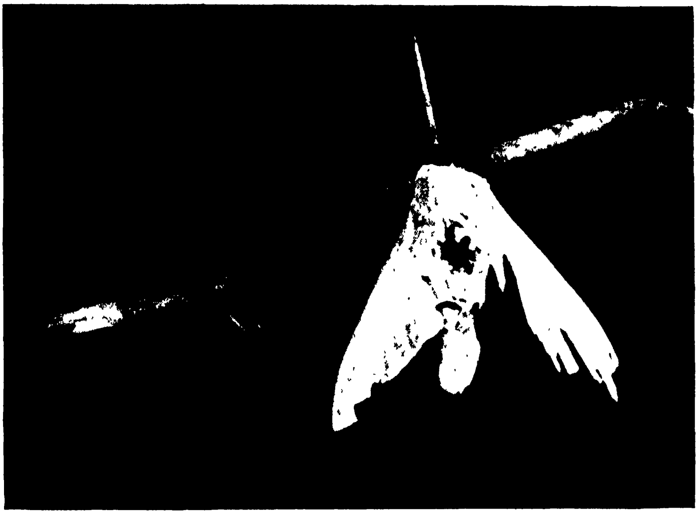

Fig. 3. Moth skewered on thorn of *Acacia farnesiana.*

In normal times coffee and copra (the dried meat of the coconut) are the most important agricultural exports. An attempt has been made to grow cotton on a commercial scale, but because of pests and perhaps for other reasons, it did not succeed. Rice was formerly planted over considerable areas, and likewise sugar cane; of the former I saw a tiny planting, and the latter is to be seen in many of the small native gardens but seldom elsewhere, and nowhere in commercial quantity. There are many home gardens and also a good deal of truck farming. The natives have added the usual vegetables to the staple taro, banana and sugar cane. Hillsides of abandoned terraces bear mute testimony to a more flourishing aboriginal agriculture. A very thick-skinned gouty-looking lemon grows abundantly along certain fields and roadsides, while the little mandarin orange is common in cultivation but also grows in the wild state. Mangoes and avocado pears are plentiful in season, but we saw only one or two breadfruit trees during our entire four-month stay in the island. Occasional hurricanes may severely damage crops, thus creating a scarcity of such fruits as bananas and papayas.

During my stay in New Caledonia I saw no large outbreaks of insect pests save perhaps of day mosquitoes, and it is presumed that these insects are locally numerous at least periodically. Certain harmful insects were so sparingly taken or found on plants of no economic value, as not to be recognized at the time as pests. However, the presence of the immature stages of some injurious insects up to the time of my departure suggested that pests might later become more abundant.

Fig. 4. Common European snail *Helix aspersa*. About natural size.

The economic insects are herewith listed according to host. The list is based on my own collecting and upon the work of others as recorded in literature. Needless to say many more insect pests remain to be recorded from New Caledonia. Species not taken by me are marked with an asterisk (*) ; those not known to occur in Hawaii are marked with a degree sign (°).

### BANANA

*Nacoleia octasema* (Meyrick)°: The banana scab moth, the caterpillar of which is a serious pest, feeds among the young bananas of the bunch. The bananas develop an unsightly scab and become more or less unsalable. The mature caterpillar is reddish with numerous small dark plates (Fig. 5). It is apparently widespread on bananas in New Caledonia and extends as far east in the Pacific as Samoa where Mr. Swezey has studied it (*The Hawaiian Planters' Record*, 45: p. 30, 1941). Mr. Swezey states: "Damage is checked by dusting with sulphur at the proper time."

*Cosmopolites sordidus* (Germar)°: The banana weevil is blackish and about the size of the sugar cane weevil borer. It is found in the tropics of both hemispheres, occurring on many Pacific Islands including Guam and Samoa. The larva feeds in the base of the banana plant and also destroys the shoots. A single adult weevil was found on an old banana plant at the base of Mount Mou, New Caledonia. It is a long-established pest on this island.

### CITRUS

Mandarin oranges of good quality are an important fruit in New Caledonia. They are common in gardens and also grow wild. In many places lemon trees with

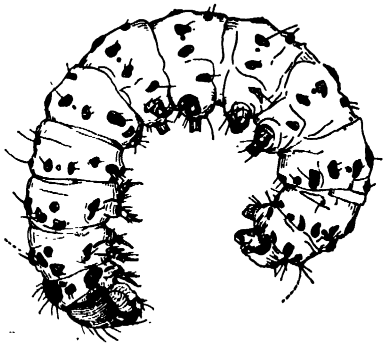

Fig. 5. Banana scab moth caterpillar (*Nacoleia octosema*). Much enlarged.

thick gouty-looking fruit grow by the wayside. Grapefruits were seen in cultivation near Mount Mou.

*Aleuroplatus* (*Orchanus*) *samoanus* Laing°: This aleurodid or whitefly is sometimes common on the leaves. Aleurodidae are related to aphids and scale insects.

*Icerya purchasi* Maskell: The cottony cushion scale, one specimen of which was taken on the twig of a tree. Isle of Pines.

*Pulvinaria* sp.: On citrus. Noumea.

*Pseudococcus citri* (Risso): Noumea.

*Pseudococcus filamentosus* (Ckll.): On citrus twig. Noumea.

*Ceroplastes rubens* Maskell: A wax scale common on the leaves of citrus, *Melaleuca* and many other plants.

*Lepidosaphes becki* (Newman): On the leaves of orange trees and on mandarin oranges in store. Noumea.

*Pseudaonidia trilobatiformis* Green°: On citrus leaf.

*Myctis profana* (Fabr.)°: Only two specimens of this bug, which is just under an inch long, were taken. To quote Froggatt (Australian Insects, p. 332, 1907): "It . . . has been found infesting the citrus orchards where it punctures the young shoots and causes them to die back." (Australia.)

*Dacus psidii* Froggatt°: The guava fruitfly attacks many kinds of fruits but favors guavas. C. Jacques has studied this pest in New Caledonia (*La mouche des fruits de la Nouvelle-Calédonie,* Rev. Agri. Nouv. Caledonie, 1938: 3133–3138, 6 figs. Noumea, August 1938).

*Papilio amyntor* Bdv.°: A fine large swallowtail butterfly (Fig. 6), the caterpillar of which feeds on the leaves of *Citrus* sp. The butterfly is common in the city of Noumea.

*Orthreis fullonia* (Clerck)°*: This fine, large, fruit-piercing noctuid moth has the proboscis modified for piercing. It attacks many kinds of fruits. The showy caterpillar feeds on the leaves of *Erythrina.*

Citrus leaf miner°: The caterpillar of a very small moth mines the leaves, beginning the mine at the margin and terminating it as a more or less inflated blotch. The moth was not reared. Dumbea.

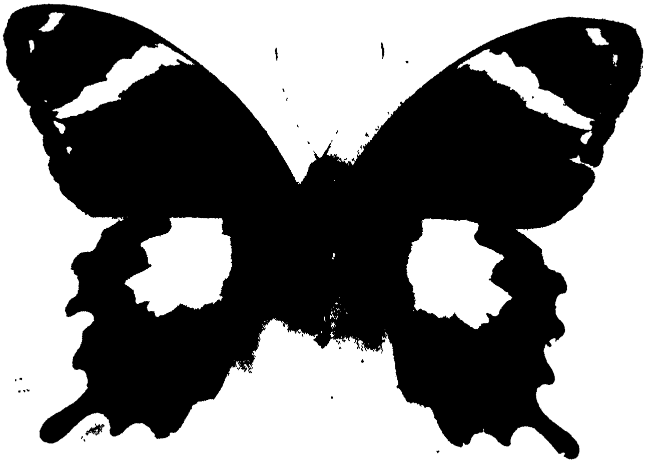

Fig. 6. Citrus swallowtail (*Papilio amyntor*). Slightly reduced.

## COCONUT

As determined in recent years, copra, the dried meat of the nut is, next to coffee, highest in export value among the agricultural products. The coconut palm is abundant in the lowlands of New Caledonia, and on the east coast there were considerable plantings of it. Many pests were attached to it as follows:

*Aspidiotus destructor* Sign.°*: The coconut palm scale is widely distributed in the Pacific. It was reported as injurious on coconut palms in New Caledonia, but was held in some control by parasites, the most important of which was an aphelinid wasp (Risbec, 1936).

*Aspidiotus hederae* Vall.: Reported by F. Laing in *The Coccidae of New Caledonia,* Ann. and Mag. Nat. Hist. (10) XI, 675–678, 1933.

*Chrysomphalus aonidum* (Linn.): This is the Florida red scale. It rather seriously damages the young fronds, producing yellowish spots which enlarge and cause a drying of the leaf tissue. La Foa, September, on young coconut palms; Noumea, September, on leaves of *Bauhinia* tree (Leguminosae).

*Ripersia palmarum* Ehrhorn: This mealybug was found in the unopened frond of a coconut palm at St. Louis in August.

*Aleurodicus destructor* Mackie°*: Neither this nor the following aleurodid is said to be very destructive to the coconut palm.

*Aleurocanthus* sp.°*:

*Phaciocephalus* sp.°: This is a slender-winged derbid leafhopper with straw-yellow wings marked by a pink and brown stripe. This insect seemed not to be injurious.

Only adults were found and these were not very common. The young do not feed upon the fronds. La Foa, October; Noumea, August.

*Graeffea crouani* (Le Guillou)°*: This large stick insect is also found in Fiji, Samoa and Tonga. It eats abundantly of the coconut foliage. It is sometimes recorded under the name of *Graeffea cocophaga* Newp.

*Hemarchus pythonus* (Westw.) °*: This is another large stick insect that damages the coconut palm. Immature walking-stick insects were occasionally seen in a forest clearing where they damage foliage.

Grasshoppers: Immense "sauterelles" or grasshoppers that stridulate were reported to me as damaging the fronds. These may have been a species of long-horned grasshoppers, the young of which were often found resting on sugar cane.

*Tirathaba rufivena* Wlk.°*: This is a pyralid moth the larva of which eats the young nuts and male flowers of the coconut. This insect ranges from Ceylon through the Solomons to New Caledonia.

*Agonoxena* sp.°*: This is a small tineid moth, the larva of which eats the leaflets under the cover of the silk cases.

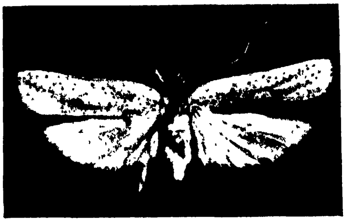

**Fig. 7.** Coconut palm moth (*Tonica* sp.?). Expanse 26 mm.

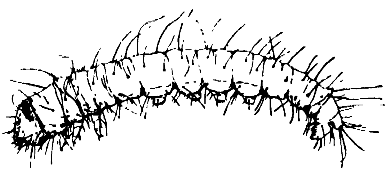

**Fig. 8.** Coconut palm larva. Length 15 mm.

*Tonica* sp.? (Oecophoridae)°: This small moth (Fig. 7) is evidently widely distributed in New Caledonia. The caterpillar (Fig. 8) does some damage to the fronds, its work somewhat resembling that of the coconut leafroller, *Omiodes blackburni* (Butl.), in Hawaii. It fastens together very strongly with silk the two sides of a leaflet or one leaflet and the adjoining one. In the retreat thus formed it eats here and there part way through the leaflet. The dull-colored caterpillar is a little less than an inch long; there is a dark band across the forehead and some dark color about the mouth. Rather long hairs arise from little brownish tubercles. When about to transform it spins a silken mat upon the upper surface of a leaf or other object and fastening the end of the abdomen in this mat, sheds its skin to become a stout pupa (Fig. 9). This pupa is sharply conical at the head, and is gen-

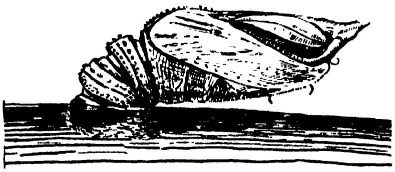

**Fig. 9.** Coconut palm pupa. Length 11.5 mm.

erally beset with little tubercles curiously tufted with short finely branched processes. The flat sole-like tail end is planted on the silk mat and the pupa literally leans backwards. The ensuing moth expands an inch or more and has blunt pale-brown forewings flecked with black, and plain brownish hindwings. La Foa, October; Touho, October 3, 1940.

*Diocalandra taitensis* (Guer.)*: This small weevil is rather widely distributed in the Pacific. It breeds in the trunk, bases of leaves, spathe of the inflorescence and the young nuts. In some islands it sometimes causes severe damage to the palm. In the Hawaiian Islands it is not considered an important coconut pest.

*Bronthispa longissima Gestro,* var. *froggatti* Sharp°: This is one of the several hispid beetles that attack the foliage of the coconut palm in the East. It is a narrow flattened insect about 9–10 mm. long, and reddish and black in color (Fig. 10). Both larva and mature beetle feed externally on the tender unexpanded leaves of the palm and thus do serious damage. I did not see this pest in quantity. It is found from New Guinea to New Hebrides (Simmonds, 1925). It also damages other species of palms. St. Louis and Mount Mou.

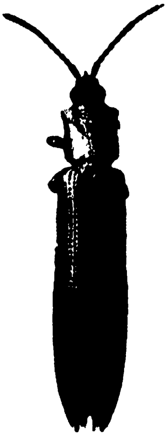

Fig. 10. Coconut hispid (*Bronthispa longissima* var. *froggatti*). Length 9.5 mm.

*Plesispa cocotis* Maulik°*: This is another hispid beetle. It is said to be less injurious than *Bronthispa.*

*Necrobia rufipes* (De Geer): This is the common widely distributed copra beetle. It is found about warehouses and copra-drying establishments.

*Rhyncophorus ferrugineus* Fabr.°*: The red palm weevil is one and one-half to one and three-quarters of an inch long. It usually follows up damage—such as wounds in the trunk—and the larva feeds within the trunk. It is considered a serious pest.

*Oryctes* sp.?°*: At Hienghene, on the east coast of New Caledonia, a note of October 4, 1940, is to the effect that the coconut palms showed occasional sheared fronds suggesting the work of this or another large dynastid beetle, although it may have been the work of another type of insect. *Oryctes* beetles are serious coconut pests in Samoa, the East Indies and elsewhere. It seems not to have been recorded from New Caledonia.

Among the works relating to coconut pests of this part of the Pacific are:

Risbec, J., 1936. *Les parasites du Caféier en Nouvelle-Calédonie.* Agron. colon. No. 226: 105–123, 1 ref. Paris, October 1936.

Lever, R. J. A. W., 1934. *Entomology and agriculture in the British Solomon Islands.* Tropical Agri. 11 :36–37.

Simmonds, H. W., 1925. *Pests and diseases of the coconut palm in the islands of the Southern Pacific.* Dept. Agri. Fiji, Bull. 16 :1–32, 3 plates.

Other papers by various authors from the Department of Agriculture, Fiji, refer wholly or in part to coconut pests.

### COFFEE

Both *Coffea arabica* Linn. and *C. robusta* Linden are cultivated in New Caledonia. Small plantations were visited at Oua Tom, the Nepoui Valley on the west coast, and at Hienghene and Nakety on the east coast where it was more extensively planted. The groves visited were shaded by *Albizzia* and other trees and, as a rule, were situated at low levels. On the east coast the groves were often among coconut palms and but a short distance from the seashore. Small plantings were found in native villages. Generally speaking the bushes bore a healthy appearance with but few pests apparent.

*Saissetia nigra* (Nietn.) : A few specimens of this armored scale—attended by ants —were found on the stem end of the berries. Hienghene, October.

*Ueana lifuana* (Montr.)° : This cicada is about one and one-fourth inches long. It seems this species chiefly that injures the coffee bush. The female cicada lays her eggs in the twigs which she pierces with her sharp ovipositor so that they may eventually break off. Such injured twigs were observed in a small coffee plantation at Oua Tom.

Moth°* : "The larvae of an unidentified moth made their galleries in the bark, and, when very numerous, ringed the trees or their branches, causing their death." (Rev. Applied Ent., 25 :223, 1937, reviewing Risbec [1936].)

*Coffearhynchus neocaledonicus* Risbec°* : This coffee weevil was found by Risbec infesting the bark and branches of coffee in mountainous districts.

*Araecerus fasciculatus* (De Geer) : This widespread tropical anthribid beetle is often destructive in stored coffee. It is also a feeder in dead wood, fruit husks, etc.

*Enicodes fichteli* Schreib, and *Enicodes montrouzieri* Montr.° : According to Risbec (1936) some New Caledonian coffee planters are of the opinion that the adults of these two longicorn beetles damage the fruits, but this was not confirmed; neither were the larvae considered injurious in coffee plantations. I found *Enicodes fichteli* rather abundant in wooded land in several localities, and at Hienghene it was beaten off coffee bushes which, however, it did not appear to damage. This insect is brownish black with some fine pale and more or less interrupted stripes. The male has much the wider head and the wing covers are attenuated in that sex. It measures up to an inch long.

*Eulota similaris* (Fer.) (Mollusca): This is a rather small, widely distributed tropical garden snail that is often a pest on vegetables and flowering plants. On Mr. Want's little coffee plantation at Oua Tom in September, this snail was present in large numbers at the bases of coffee bushes where it was evidently passing the dry season. It was considered injurious because it ate the bark at or near the ground.

J. Risbec has published a paper on the coffee pests of New Caledonia (*Les parasites du cafêier en Nouvelle-Calédonie,* Agron. Colon. No. 226:105–123, 1 ref., Paris, October 1936).

## CORN

*Aphis maidis* Fitch: Corn aphis. On corn. Col de la Pirogue, September.

*Peregrinus maidis* (Ashm.): Corn leafhopper. St. Louis, July, on sugar cane—sparse. Also on Johnson grass and a hairy, broad-bladed grass not identified. Isle of Pines, October, on sugar cane.

*Heliothis armigera* (Hubn.): Corn-ear worm. On various crops.
*Marasmia trapezalis* (Guen.)°: Corn leafroller. Generally distributed. This pyralid moth was not observed on corn.

*Monolepta semiviolacea* Fauv.°: This small leaf beetle is orange-yellow above and mostly blackish beneath. The disc of the thorax lacks a transverse groove. It is a bad pest on corn, turnips and other crops. Adults on the foliage, the larvae underground at roots.

Large Red-billed Coot (*Porphyrio* sp.?): In New Caledonia this bird or a related form is sometimes said to be a pest because it damages corn as seed in the ground, or on the cob. In times of drought banana plants are also injured.

Among beneficial insects frequenting corn plants are small anthocorid bugs.

## COTTON

I examined a small planting of cotton at Oua Tom in September. Aphis and mealybugs were found at the bases of the squares or the bolls.

*Oxycarena lugubris* (Montr.)°: This small, chiefly black and white bug was found in bolls that had been eaten by pink cotton bollworms. The bug is common in Australia. In other countries related species are also associated with cotton, to which they do some damage.

*Dysdercus sidae* Montr.°: This is one of the cotton-stainer bugs. I took but few specimens in New Caledonia. It is a serious cotton pest in Queensland where Ballard and Evans found this as well as *Tectocoris lineolata* (Fabr.) to be: "...the chief insects that cause internal boll-rots and stained cotton." (Bul. Ent. Res., 18:405–432, 1928.) *D. sidae* is an Austro-Oriental species.

*Tectocoris lineolata* (Fabr.)°: This is a large stout bug of which there appear to be several varieties. It is orange-yellow with some markings of iridescent blue or green. It injures hibiscus and cotton and has been found on other plants. It did not appear common at the time of my visit. It is rather widely distributed in Australia.

For a treatise on this insect consult Ballard and Holdaway in Bull. Ent. Res., 16:329–346, 1926, illustrated.

*Heliothis armigera* (Hubn.): The corn-ear worm caterpillar attacks cotton, buds of roses, etc. It is often found in truck gardens.

*Prodenia litura* (Fabr.): The caterpillar of this armyworm is sometimes found on cotton.

*Earias huegeli* Rogenh.°: This is one of the bollworms and has been reported as the most serious cotton pest in New Caledonia. It occurs in Australia and well out in the Pacific. Risbec mentions a pentatomid bug as an enemy of this noctuid (*Un pentatome parasite de la chenille Epineuse du Cotonnier,* Compte Rendu Acad. Sci., France, 193:247–250, 1931).

*Earias luteolaria* Hamp.°: A single larva of a species of *Earias,* probably one of the above two species, was found on cotton at Oua Tom. Also in Ceylon and Queensland.

*Platyedra scutigera* Holdaway°: The pink bollworm of Queensland. The small, variegated brownish moth is closely related to the well-known pink bollworm (*P. gossypiella* Saunders). Moths were reared from cotton bolls at Oua Tom.

This insect was described from Queensland. For a discussion on this species the reader is referred to F. G. Holdaway—*The pink bollworm of Queensland,* Bull. Ent. Res. 17:67–83, 1926, 1 pl., 1 map.

Like other cotton pests in general this insect has other host plants related to cotton.

*Tetranychus* (*Eutetranychus*) *neocaledonicus* Andre°*: This acarid mite has been reported damaging cotton in New Caledonia.

### RICE AND OTHER GRASSES

There seemed to be very little rice cultivated on the island. However, rice pests that also feed on other grasses were present. Some of these are:

*Tettigonella spectra* Distant°: A large pale leafhopper, also on sugar cane.

*Nezara viridula* (Linn.)°: Reported bad on rice in various tropical and sub-tropical countries.

*Leptocorisa acuta* Thunb.°: A rather large malodorous bug that is a well-known rice pest in the Orient.

Grasshoppers: Several species of short-horned grasshoppers that attack grasses in general.

*Spodoptera mauritia* (Boisd.): Armyworm.

*Melanitis leda* (Linn.)°: The caterpillar of this butterfly sometimes feeds on the rice plant.

### SUGAR CANE

Sugar cane was formerly cultivated in fairly large plantings in a few places in New Caledonia, but is now restricted almost entirely to very small patches in native gardens. Striped varieties were common. It was frequently in rather poor condition, and insect pests, although usually not in large numbers on this plant, were often numerous in species.

*Neomaskellia bergii* (Sign.)°: This aleurodid was found on cane in Noumea and St. Louis but appeared to do little damage. It occurs in patches on the underside of the leaves. The adults are somewhat aphis-like, with broad wings irregularly marked in gray and off-white. The eggs are deposited in somewhat of a circle. The dark pupal cases are margined with white. The insect was usually attended by *Anoplolepis longipes* (Jerd.), an active brown ant not occurring in Hawaii.

This aleurodid is widely distributed in the East Indies and extends eastward in the Pacific as far as Samoa.

Aspidiotiform scale insect°: A single, little yellow scale insect found on sugar cane in a garden in Noumea.

(*Aphis sacchari* Zehnt., the common sugar cane aphis widespread in the Pacific, was not found in New Caledonia.)

*Pseudococcus boninsis* Kuwana: The gray sugar cane mealybug was the only species found on sugar cane. It was not abundant and was attacked by the ladybeetle *Cryptolaemus montrouzieri* Muls.

*Eumetopina flavipes* Muir°: A small rather slender delphacid leafhopper, mainly blackish above, and part of the body beneath pale yellowish (Fig. 11). It was generally the most abundant of the several species of leafhoppers found on sugar cane. Its habits are much like *Perkinsiella* leafhoppers. It also occurs in the New Guinea area.

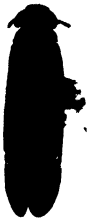

**Fig. 11.** Sugar cane leafhopper (*Eumetopina flavipes*). Length 4.5 mm.

*Perkinsiella rattlei* Muir°: This delphacid leafhopper is a close relative of *P. saccharicida* that is found in Hawaii. It was quite scarce at the time of my visit, being taken at St. Louis, Nepoui, and Hienghene. It is probably this species or *Eumetopina flavipes* that is the vector of Fiji disease, widespread in New Caledonia.

*P. rattlei* was reported from New Caledonia by F. Muir (Ann. and Mag. Nat. Hist., 14 (10) :578, 1934) from specimens collected by T. D. A. Cockerell in 1928.

*Peregrinus maidis* (Ashm.): The corn leafhopper was scarce, single specimens being taken at St. Louis and the Isle of Pines.

*Tropidocephala* sp. near *brunnipennis* Sign.°: On tall grass. Leafhoppers of this genus are common on sugar cane elsewhere. It is one of the Delphacidae.

*Phaciocephalus rubrofasciata* (Distant)°: This is a slender-winged, straw-colored derbid leafhopper (Fig. 12) with a brown and red stripe on the tegmina. It was often rather common on sugar cane but the young were never seen upon the plant.

**Fig. 12.** Sugar cane derbid (*Phaciocephalus rubrofasciata*). Length 6 mm.

St. Louis and Hienghene. It was described as *Nisia rubrofasciata*° in Ann. and Mag. Nat. Hist., 6 (9) :462, 1920.

*Phaciocephalus* sp.: Two specimens from sugar cane near Houailou differ slightly from the above in their duskier wing stripe.

*Phaciocephalus* sp.°: A single specimen of a straw-yellow species with a black stripe taken on sugar cane on the Isle of Pines.

*Eocenchrea* sp.°: One specimen of this dusky derbid leafhopper was taken at St. Louis on sugar cane, on which it is most probably not specific.

*Tetigoniella spectra* Distant (=*Tettigonia albida* Sign.)°: This a large whitish-to-greenish yellow cicadellid leafhopper (Fig. 13), with four dark spots on the top of the head and the wing veins contrastingly dark. It is widely distributed in New Caledonia where it occurs on various grasses, including sugar cane. The immature leafhoppers were also seen on sugar cane, the adults being the more numerous on the plant. In India it is a common rice leafhopper. It is also found in the Australian region and extends into the Pacific as far as Fiji.

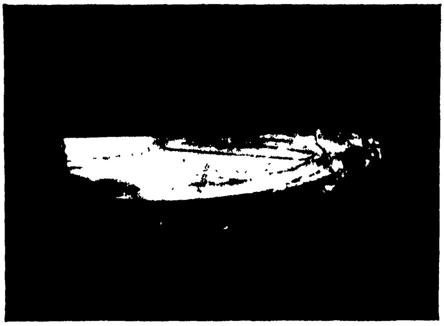

**Fig. 13.** Sugar cane leafhopper (*Tetigoniella spectra*). Length 9 mm.

*Ereunetis flavistriata* Walsm.:. Sugar cane bud moth. As in Hawaii the larva of this little moth feeds chiefly on the innerside of the cane sheath, usually a dry one;

less often it eats the surface of the rind and occasionally attacks a bud. The insect does little damage.

*Cosmopteryx dulcivora* Meyrick°: Sugar cane midrib leaf miner. The larva of this tiny narrow-winged moth bores the midrib in an irregular zigzag manner (Fig. 14) so that the affected part together with a little of the adjoining leaf tissue reddens and finally becomes dead and dry, even to the apex of the leaf. The insect, however, does only minor damage, and is held in some check by a hymenopterous parasite, a pupa of which was found in one of these mines. St. Louis and Hienghene.

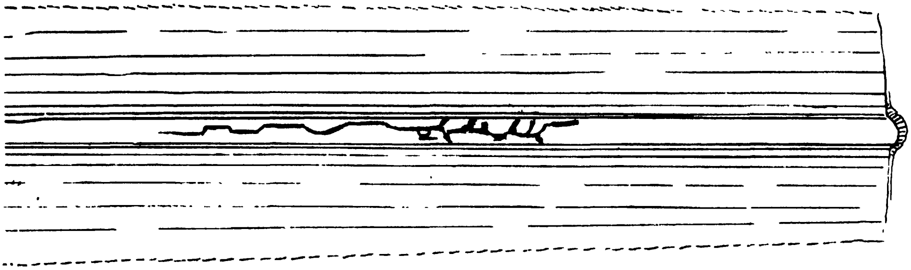

**Fig. 14.** Sugar cane midrib leaf miner (*Cosmopteryx dulcivora*) mine in section of sugar cane leaf. About natural size.

Moth borer°: On October 5, near Ba-Houailou, in a small planting of red-stemmed Java cane, a small caterpillar was found in a dead top stubble. It had bored a short distance into the living tissue of this old cane stem. On October 8, at Nakety, another moth caterpillar was found under conditions similar to the first. In both cases the larvae seemed to be feeders primarily in rotting cane—or other plant tissue. Neither was reared.

*Marasmia trapezalis* (Guenee)°: This leafroller moth was occasionally seen. What may have been its caterpillar was observed tying together the younger leaves of a tall wild grass. Evidence of a leafroller was found on sugar cane in Noumea in late September. It is a well-known insect that also attacks corn but is not considered a serious pest.

*Spodoptera mauritia* (Boisd.): Armyworm. One adult moth taken at Noumea.

*Melanitis leda* (Linn.)°: This brown butterfly is widespread in the Orient, as one variety or another, and extends as far east as Samoa. The caterpillar feeds on various grasses—occasionally sugar cane, rice and corn. In New Caledonia the butterflies were seen about sugar cane in a native garden but none of the caterpillars was found (St. Louis). At Nepoui this crepuscular butterfly was seen laying its eggs on a large sedge that was growing alongside a wooded stream, and one adult was reared in this locality from a caterpillar found on this sedge. It is evidently of little or no importance on sugar cane. The writer saw a caterpillar of this butterfly feeding on sugar cane in Tutuila, Samoa, June 1940.

*Calendra* sp.°: Two specimens of a rather small undetermined weevil were found at Ba-Houailou resting on an injured portion of a sugar cane stalk. It is probably not a feeder in living plant tissue.

*Tarsonemus* mite ?: There was evidence of a stalk mite occurring very sparsely on sugar cane. The sugar cane leaf mite (*Tetranychus*) was not found.

*Chelisoches morio* (Fabr.): This is the same large and flat, black earwig that is so often seen on sugar cane in Hawaii. It is common in New Caledonia.

Ants: The most obvious ant on sugar cane in New Caledonia is *Anoplolepis longipes* (Jerd.).° It attends aleurodids and probably leafhoppers. Other ants found on this plant were *Prenolepis* (*Nylanderia*) *bourbonica* Forel, a species of *Pheidole,*° *Tapinoma melanocephalum* Fabr., *Cardiocondyla* and *Rhyzomyrma*° sp.?

## SUGAR CANE DISEASES

Collections were made of sugar cane leaves and stem portions that showed signs of disease or of abnormal markings. These collections were submitted to J. P. Martin, pathologist at this Experiment Station for determination. It was found that Fiji disease was common and widespread in New Caledonia on sugar cane growing in native gardens. Eye spot and brown stripe were also present, as well as leaf burn. Good examples of sectional chlorosis were found in regions where the temperature was said to be at times relatively low.

## TARO

A staple food of the indigenous people.

*Aphis gossypii* Glover: This common plant louse is found on taro and on many other plants.

*Megamelus proserpina* Kirk.: Taro leafhopper. Not seen in injurious numbers. Parasitized by a dryinid wasp and attacked by *Cyrtorhinus fulvus* Knight, an egg-sucking bug. St. Louis.

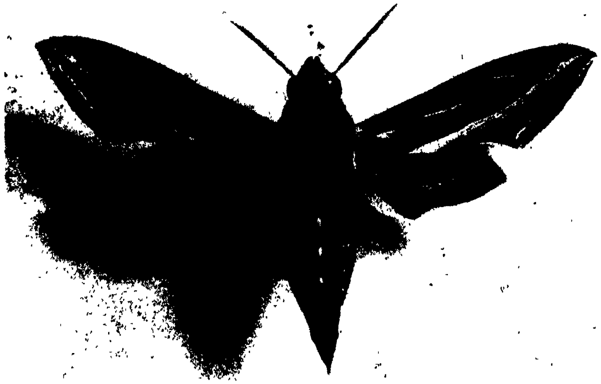

**Fig. 15.** Taro sphinx moth (*Hippotion celerio*). About natural size.

*Prodenia litura* (Fabr.)°: This armyworm feeds on several kinds of crops including taro. It was not a common insect at the time of my visit.

*Hippotion celerio* (Linn.)°: This handsome sphinx moth (Fig. 15) has a wing expanse of about three inches. It is of a general olive-brown color, the body and forewings marked with silvery dashes, the hind wings suffused with pink. The caterpillar (Fig. 16) is brown or green with an eye-like spot on the swollen thorax and a horn above at the tail end. It is quite general on taro in New Caledonia and also on the ornamental Caladium plants of the same family. Frequently it almost defoliates these plants. This insect is widely distributed in the tropical Pacific as far east as Samoa, Tahiti and Moorea, occurring also in Africa, India, and parts of Europe.

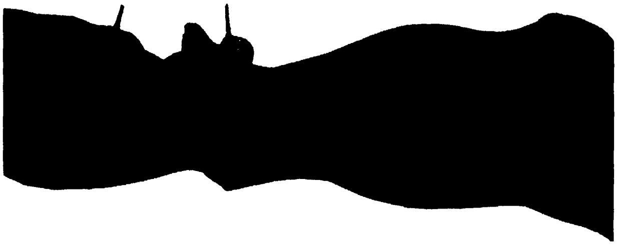

Fig. 16. Taro sphinx moth caterpillars.

A probable enemy of the caterpillar was noted at Nepoui, where a mass of braconid wasp (*Apanteles* ?) cocoons were found on a taro leaf near which the caterpillars were present.

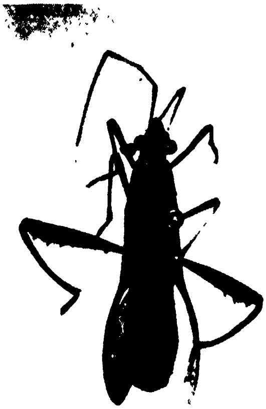

Fig. 17. Bean bug (*Riptortus annulicornis*). Length 15 mm.

Fig. 18. Green vegetable bug (*Nezara viridula*). Length 16 mm.

R. J. A. W. Lever gives a good account of the taro sphinx in Fiji (Agric. Jour. Fiji, 11: 38–42, Ent. Notes. 1 fldg. plate, Suva, 1940). The damage that this insect does to taro is well figured by G. H. E. Hopkins (*Pests of economic plants in Samoa and other island groups,* Bull. Ent. Res. 18: 23–32, 1927).

## Truck Crops

### BEANS AND PEAS:

Aphids: On beans, Nepoui.

Aleurodidae: Adult white flies were sometimes found on beans.

*Pseudococcus citri* (Risso) : This mealybug was found in rolled up leaves of pigeon peas.

*Riptortus annulicornis* (Boisd.)° : A large active bug (Fig. 17) that is quite common on climbing bean plants.

*Nezara viridula* (Linn.)° : Green vegetable bug (Fig. 18). On beans, cucurbits and other plants.

*Leptoglossus australis* (Fabr.)° : Mr. Swezey reports this large bug occasional on bean vines on the island of Guam. I found this insect quite rare in New Caledonia.

*Nemashema modesta* Montr.° : This small obscurely colored longicorn beetle may be beaten from bean vines, cotton plants and *Hibiscus tiliaceus*. It probably feeds on the dead stems.

*Acrocerops* sp.° : A tiny red caterpillar of a tineid moth that mines the bean leaves. It belongs to a group or a species widely distributed in Oceania.

*Nacoleia diemalis* (Guen.)° : A leafroller caterpillar (Fig. 19—moth) on beans. Nepoui.

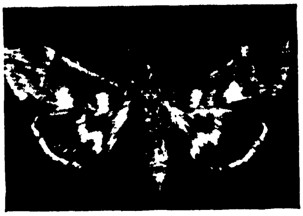

Fig. 19. Bean leafroller moth (*Nacoleia diemalis*). Wing expanse 21 mm.

*Plusia chalcites* (Esper.) : A looper caterpillar. On beans, Nepoui.

*Heliothis armigera* (Hubn.) : Corn-ear worm. On peas, Noumea.

*Cosmolyce baetica* (Linn.) : The blue bean butterfly. Not found to be common.

### CABBAGES AND OTHER CRUCIFERS:

Cabbages and other crucifers are an important element in the truck gardens. We saw some mighty heads of cabbage in New Caledonia.

*Brevicorne brassicae* (Linn.) : Cabbage aphis. Found on flowering head of turnip. St. Louis.

*Hellula undalis* (Fabr.) : The cabbage webworm is a well-known pest in the Pacific. It was taken in the moth stage.

*Liriomyza pusilla* (Meig.) : The maggot of this tiny black and yellow fly mines the leaves of many kinds of plants, including crucifers. As in Hawaii, it is often rather heavily parasitized by small wasps.

*Monolepta semiviolacea* Fauv° : This yellowish chrysomelid beetle attacks the leaves of crucifers and other plants. It is a serious garden pest.

*Crocidoloma binotalis* Zeller°: This is a destructive pest (Fig. 20) on Chinese cabbage and probably other crucifers. The work of the caterpillar among the younger leaves is very untidy.

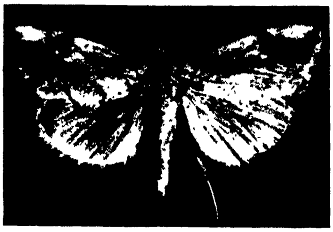

Fig. 20. Moth on cabbage (*Crocidoloma binotalis*). Wing expanse 25 mm.

*Helix aspersa* Müll.°: This large European snail (Fig. 4) is common in gardens in New Caledonia where it sometimes does considerable damage to such vegetables as cabbage, wedging itself among the inner leaves and eating great holes in them. Observed in Noumea.

The British naturalist J. J. Walker who visited New Caledonia in 1900 speaks of the abundance of this snail in Noumea and the New Hebrides (Ent. Mo. Mag. 13 (ser. 2), 1901, page 190). It was introduced presumably to be eaten, as it was on the Pacific coast of the United States where it is likewise very injurious in gardens.

*Veronicella leydigi* Simroth: This large leathery black slug, widespread in the Orient, was observed on the east coast of New Caledonia. It is common in Honolulu where it sometimes injures low tender foliage.

CUCURBITS:

Aphis sp.: On squash, Noumea.

*Leptoglossus australis* (Fabr.)°: This large bug attacks various cucurbits and some other plants. Uncommon.

*Nezara viridula* (Linn.)°: Green vegetable bug (Fig. 18).

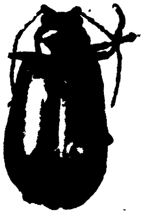

Fig. 21. Leaf beetle (*Aulacophora similis*). Length 6.5 mm.

*Aulacophora similis* Oliv.°: This beetle (Fig. 21) is a bad pest on Cucurbitaceae and other plants.

*Monolepta semiviolacea* Fauv.°: Somewhat resembling the preceding beetle. A pest on many crops.

SWEET POTATO:

The sweet potato is an important garden crop in New Caledonia.

*Heliothis armigera* (Hubn.): The corn-ear worm is occasionally found on sweet potatoes.

*Herse convolvuli* (Linn.)°: Morning-glory hawk moth. Several caterpillars of what was probably this species were found on sweet potato vines at Hienghene. The largest of these went into the ground to pupate but instead of a moth, yielded several large parasitic flies (Tachinidae). This sphinx moth is related to *Herse cingulata* (Fabr.), an American species found in Hawaii and which feeds on sweet potato and related plants.

*Bedellia* sp.°: A tiny moth the caterpillar of which mines the leaves of the sweet potato plant and pupates freely in a web on the leaf. It is closely related to *Bedellia orchidella* Walsm., the sweet potato leaf miner of Hawaii.

*Batatarhynchus destructor* Hustache°*: A sweet potato weevil reported attacking sweet potatoes in New Caledonia.

PLANTS OF THE TOMATO FAMILY:

Aleurodidae: White flies were occasionally seen on potato foliage. Noumea.

*Empoasca flavescens* (Fabr.): This is a tiny greenish leafhopper. On potato foliage, Noumea.

*Mirid* bug°: A small and delicate pale-green bug. On tomato, St. Louis.

*Engytatus nicotianus* (Konigsb.)°: Determined by Dr. R. L. Usinger. This bug is a tobacco pest. Taken on a species of white-flowered Datura.

*Nezara viridula* (Linn.)°: This insect (Fig. 18) was found damaging uncultivated tomatoes. Hienghene.

*Prodenia litura* (Fabr.)°:

*Heliothis armigera* (Hubn.): The caterpillars sometimes damage tobacco, tomato, and potatoes.

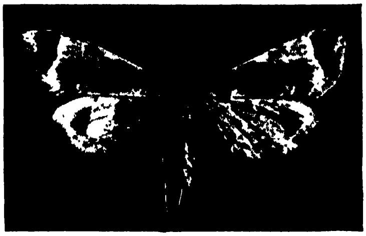

**Fig. 22. *Sceliodes cordalis.* Expanse 28 mm. The caterpillar feeds on solanaceous plants.**

*Sceliodes cordalis* (Dblb.)°: The reddish caterpillars of this pyralid moth (Fig. 22) have been recorded from the green berries of the potato in New Zealand, egg-plant in Australia, and they also attack related plants. At Noumea the caterpillars were found in the capsules of a white-flowered Datura.

*Phthorimaea operculella* (Zell.): Potato tuber moth. Caterpillars in potato plants, Noumea.

### TERMITES OR "WHITE ANTS"

G. F. Hill in his book *Termites* (Isoptera) *from the Australian Region* (Council for Scientific and Industrial Research, 1942, Melbourne) records six species of termites from New Caledonia, including the Loyalty Islands. Three or four of these and a new record were found on the present survey. There is little doubt but that additional species are present on this island. No termite mounds, such as occur in great abundance and variety in Australia, were seen in New Caledonia, although two small mounds that I took to be fallen, semi-carton nests were found in the Thi River forest near St. Louis. Termites were secured from these nests.

The New Caledonian termites are as follows:

*Calotermes (Neotermes) rouxi* N. & K. Holmgren°: In dead branch and at light. The determination of this termite is not certain. Noumea and an islet near Yate, October.

*Calotermes (Neotermes) sarasini* N. & K. Holmgren°: I took a winged adult of what appears to be this species. Thi River forest, November. Recorded by Demant (1914) as a pest of cacao in Samoa. (See G. H. E. Hopkins *Pests of Economic Plants in Samoa and Other Island Groups,* Bull. Ent. Res. 18: 23–32, 1927.)

*Calotermes (Neotermes) semilunaris* N. & K. Holmgren°*: Recorded from the Loyalty Islands.

*Calotermes (Cryptotermes) albipes* Holmgren°*: Recorded from New Caledonia and the Loyalty Islands.

*Calotermes (Cryptotermes) canalensis* N. & K. Holmgren°: In dead branch, Noumea. It is probably a species of *Cryptotermes* that damages buildings in Noumea.

*Prohinotermes inopinatus* Silvestri°: Specimens were taken at Prony Bay in October. Apparently a new record for the island. Found also in Samoa and Fiji.

*Microceratermes novae-caledoniae* N. & K. Holmgren°: Yahoue Valley, August, under stone; Thi River valley, from two semi-carton nests. Again from G. H. Hill's book, on page 437, I quote: "*Biology.* Holmgren records one of his series as having been found in an earthy nest about a half metre high."

### MISCELLANEOUS

Leafhopper°: A tiny green cicadellid leafhopper was found in moderate numbers on turnips and carrots.

*Hymenia recurvalis* (Fabr.): As in Hawaii the glassy-green caterpillar of the amaranth webworm is a pest on spinach. It also feeds on *Portulaca.*

Short-horned grasshoppers or locusts: Grasshoppers have done considerable damage to pasture lands, sugar cane and other crops. I did not see grasshoppers in epidemic proportions. About the dry grassy hills of Noumea particularly, one medium-large and three large species were noted, as follows: *Ailopus tamulus* (Fabr.)°:

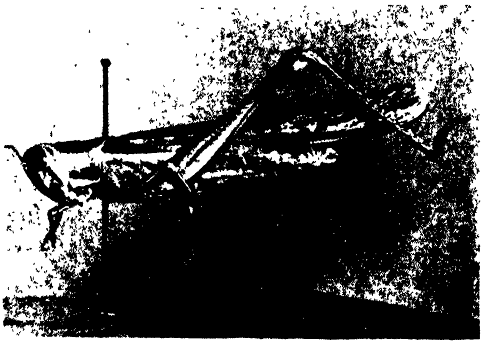

Fig. 23. *Austracris guttulosa illepida.* Length from head to wing tips 55 mm.

What appeared to be this medium large species was common. *Austracris guttulosa illepida* (Walk.) (=*Acridium neo-caledonicum* Finot)°: A slender long-winged species (Fig. 23) with pale stripes on thorax and outer wings. Among grass. A specimen observed ovipositing in a path. This insect has much the appearance of the bird-wing locusts (*Schistocerca*) of America. *Valanga rouxi* Willemse°: A large rather thickset, chiefly brownish gray insect with speckled wings. It seems addicted to trees and shrubs rather than to keeping on the ground. *Locusta migratoria danica* (Linn.)°: A large heavy species with a rather sharply crested pronotum and some green on head, thorax, and hind legs, the tibiae of which are bright red. One of the famous migratory locusts of the old world.

Lantana Insects: Both the lantana leaf bug (*Teleonema scrupulosa* Stal.) and the lantana seed fly (*Ophiomyia lantanae* [Froggatt]) were found well established on *Lantana camara* at Noumea. These two insects were introduced from Fiji to which islands they were brought from Hawaii.

*Cactoblastis cactorum* Berg: This pyralid moth borer in Opuntia cactus introduced from Australia has done good work here.

Nutgrass (*Cyperus rotundus* Linn.) enemies: *Bactra truculenta* Meyr., the common nut grass moth borer was reared from nut grass at Noumea. An undetermined moth borer, somewhat resembling the above was also reared from nut grass at Noumea.

Milkweed (*Asclepias curassavica* Linn.): This weed with pretty orange-red flowers is well distributed in the island but seemed not to be a pest. The relative scarcity of this plant has been attributed to the attacks of the larva of a lepidopterous insect called *Papilio leratii.* See *The Macrolepidopteron, Papilio leratii, as a natural means of controlling Asclepias curassavica, a weed growing in New Caledonia,* Paladini, F. (Sr.), Revue agricole, *77*: 3–4, Noumea, February 1922, from Review of Science and Practice of Agriculture, Inter. Inst. of Agric., Rome, 13: *773*, 1922. This savors largely of the monarch butterfly, *Danaus plexippus* (Linn.), which is found in New Caledonia.

*Aphis nerii* (Fonscolombe [=*A. lutescens* Monell]) was found on this milkweed.

Arctiid moths: The caterpillars of two arctiid moths, *Argina cribraria* Clerck, orange-yellow with black spots, and *Utetheisa pulchelloides* Hamp., form *stigmata* Roths (Fig. 24), white, red and black, attack various plants. *Argina cribraria* is a pest of sunn hemp in India.

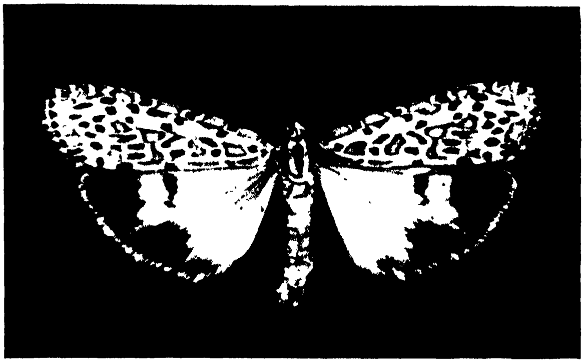

Fig. 24. *Utetheisa pulchelloides*, form *stigmata*. Wing expanse 36 mm.

*Euproctis* sp. (Lymantridae)°: This is a small species of brown-tail moth; the female is white and the male brownish with plumose antennae (Figs. 25, 26). It was found common on shade trees, chiefly *Delonix regia* (Bojer) in Noumea. Its hairy caterpillar spins a whitish cocoon found singly or in groups on the tree trunks. Other and larger cocoons on or under the bark of shade trees indicate the presence in season of additional harmful caterpillars.

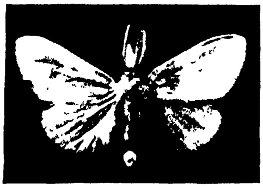

Fig. 25. Brown tail moth *Euproctis* sp., male. Wing expanse 18 mm.

Bagworms (Psychidae)°: Large bagworm cases were found suspended on trees.

Noctuid Caterpillar: On water hyacinth (*Eichhornia*). In Noumea a variegated moth caterpillar was observed eating the pseudobulbs of this plant.

Asplenium fern moth°: Caterpillars of a pyralid moth hatching from a mass of

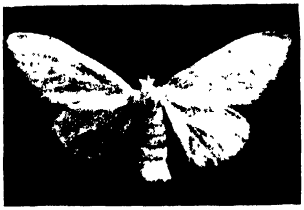

Fig. 26. Brown tail moth, *Euproctis* sp., female. Wing expanse 23 mm.

imbricated eggs attack the fronds of the bird's nest ferns in the forest (Figs. 27, 28). The caterpillars, at least at first, feed gregariously on the underside of the fronds, eating out unsightly patches (Fig. 29). The young caterpillars have black heads and glassy-green bodies; later on, the head is only speckled with dark while the body is rather sparsely provided with stiff black hairs.

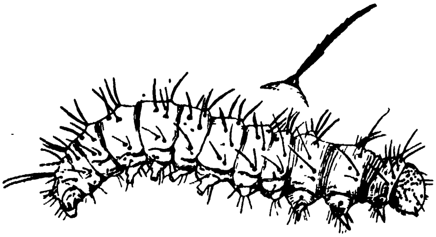

Fig. 27. Caterpillar on bird's nest fern (*Asplenium* sp.). Length about 9 mm.

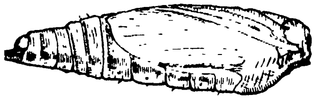

Fig. 28. Pupa on bird's nest fern (*Asplenium* sp.). Length 7 mm.

Staghorn Fern (*Platycerium*): This fern which grows wild in the forest is often seen in gardens and parks. An aphid (*Myzus* sp.)° was found on it at Noumea.

Orchid Pests: A certain wide-leafed ground orchid was found infested by the scale *Saissetia hemispherica* (Targ.), while in the thickish leaves of *Dendrobium* sp. were found the mines of a tiny caterpillar,° several dried up little moths with banded wings being present in the emergence chambers. Doubtless there are many other insects harmful to the numerous species of Orchidaceae found in New Caledonia.

*Xystrocera globosa* Oliv.: This is a rather large longicorn beetle that inhabits many Pacific islands. Remains of a dead adult and several grubs were found in the trunk of a dead peach tree in a garden in Noumea. The insect is a feeder in dead or unhealthy timber.

Skipper Butterfly (*Badamia exclamationis* [Fabr.])°: The "badamier" or tropical almond (*Terminalia catappa* Linn.), our "false kamani," is the food plant of the caterpillar of this swiftly flying butterfly (Figs. 30, adult; 31, caterpillar; 32, pupae). The eggs are at first green but eventually turn bright red. The caterpillar when well grown is a striking insect with its orange head and greenish yellow body that is strongly striped and banded with black. It makes a retreat, folding over the edge of a leaf or fastening portions of leaves together. The mealy pupa is formed in such a retreat. A small potted *Terminalia* tree in the hotel garden was almost defoliated by successive broods of this caterpillar, few of which however appeared to transform into butterflies.

INSECTS ATTACKING FOREST TREES:

A few fragmentary notes are offered here.

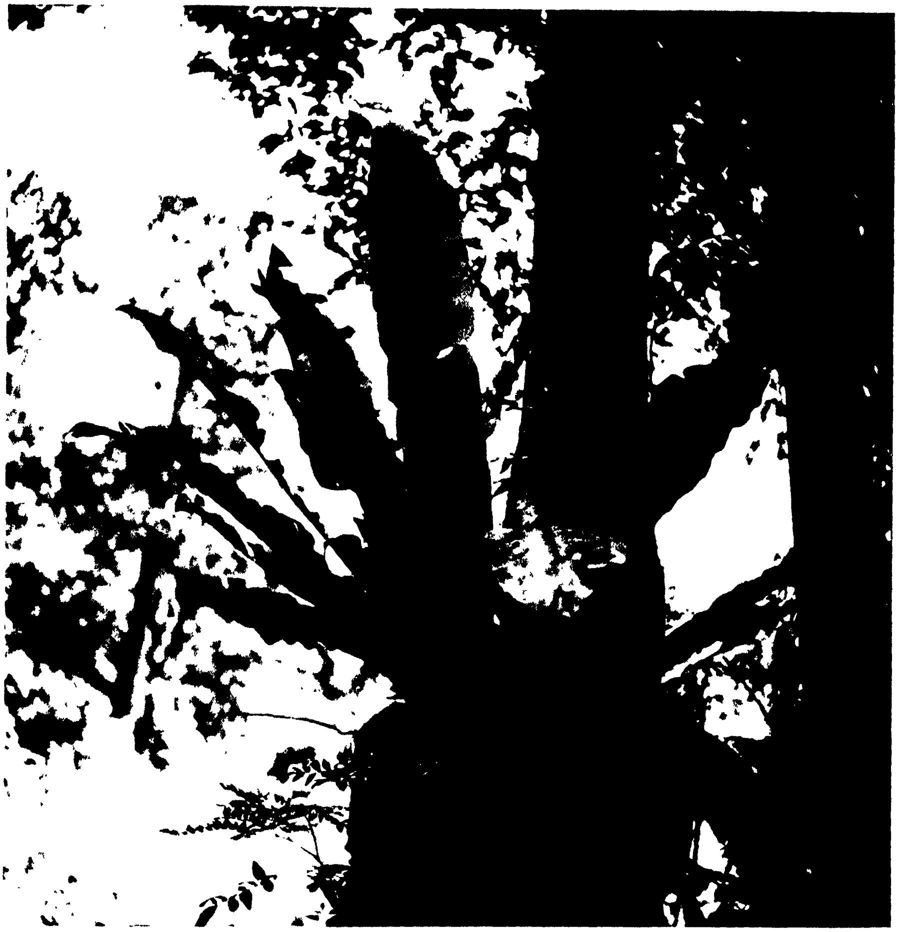

Fig. 29. Damage done by caterpillar to Asplenium fern.

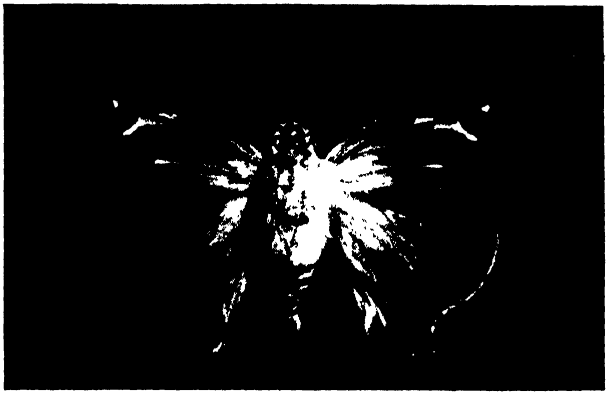

**Fig. 30.** *Badamia exclamationis,* skipper butterfly on *Terminalia catappa.* Wing expanse 50 mm.

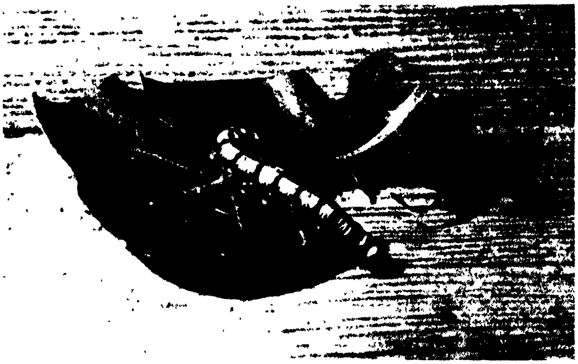

Fig. 31. *Badamia exclamationis* caterpillar. Length about 30 mm.

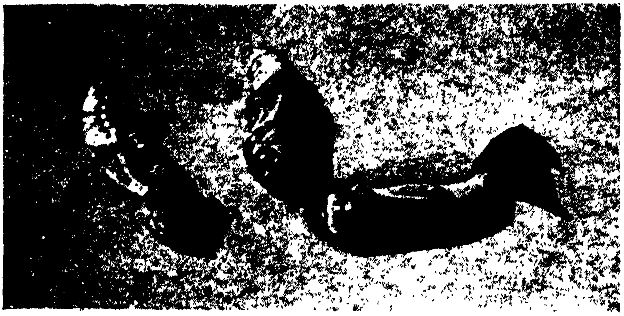

Fig. 32. *Badamia exclamationis* pupae. Length 20 mm.

The tall "pin colonnaire" (*Araucaria Cookii*) a conspicuous tree in certain lowlands of New Caledonia, and particularly on the coral islets to the south, is much employed in coarser building work. The lumber is sometimes damaged by a large grub° which makes borings that are oval in cross section. Considerable quantities of coarse sawdust may be found under such infested wood. The culprit is probably the grub of a very large cerambycid beetle, and I was informed by a lumberman on the Isle of Pines that this insect works in the logs with a very audible crunch-crunch!

A small species of *Grevillea* which grew on the mineralized soil had some of its leaves mined by the larva of a small moth.° An eulophid wasp bred from such leaves was probably parasitic on the caterpillar.

There are several species of *Casuarina* in New Caledonia. On the hills behind Noumea are individual trees or thickets of the small *Casuarina collina* (?) upon which one finds a tiny buprestid beetle; a white diaspine scale; the caterpillars of one or more species of geometrid moths; while a cecidomyid midge is often associated with gall formation on the fine twigs. A larger species of *Casuarina* bears larger galls on woody branches and these also appear to be associated with a midge.

The Indian wax scale (*Ceroplastes ceriferus* [Anderson]),° (Fig. 33), occurs on bracken fern (*Pteridium sp.*) and on the branches of shrubs in mineralized areas. This sticky, white scale, which may occur in large compact groups on the plants, is conspicuous for quite a distance, and my first view of it was in scanning a hillside from the automobile carrying us across the central mountain chain.

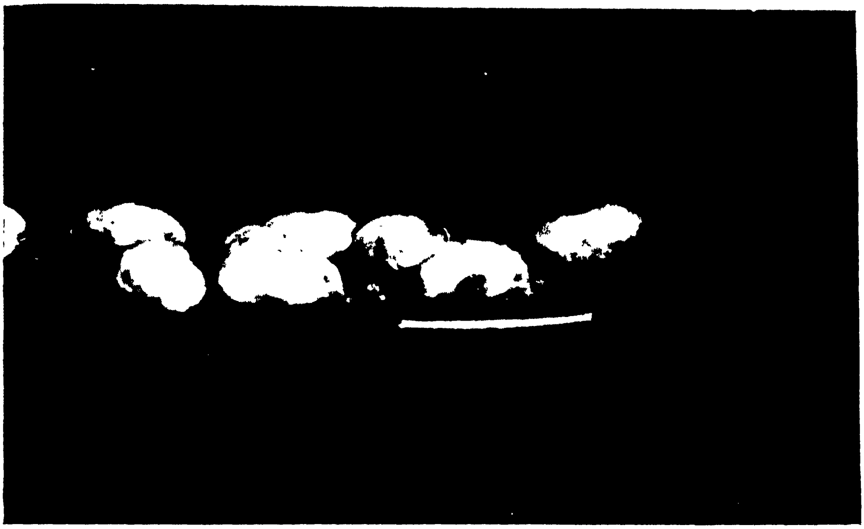

Fig. 33. Indian wax scale (*Ceroplastes ceriferus*).

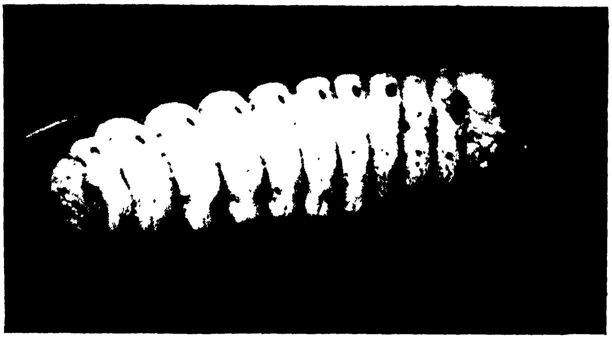

Fig. 34. Grub of a large longicorn beetle in *Aleurites* sp.

The "bancoulier," which is our kukui tree (*Aleurites moluccana* Willd.) is abundant in New Caledonia, and fallen and decaying specimens are a veritable gold mine for the entomologist, particularly to the searcher after beetles. The trunk of dead trees are commonly bored by the very large grub (Fig. 34) of a longicorn beetle. The larva and pupa of this beetle are considered a delicacy by the Melanesians and are also much sought after by the crows. Between these two hazards and the visiting entomologist this beetle should fare badly. Before pupating the grub cuts a lidded door in the bark (Fig. 35) to facilitate the exit of the adult. Such lidded doors are also made by other species of longicorns such as *Lagocheirus obsoletus* Thoms. in the Hawaiian Islands.

The niaouli tree (*Melaleuca leucadendron* var. *viridiflora*) is attacked by many species of insects, which together with their enemies and other associates combine to form a very interesting biota. Some of these organisms are: The scale *Ceroplastes rubens* Mask. is common on the leaves, and its presence is often indicated by black smut. The caterpillars of at least three species of moths are attached to this tree;

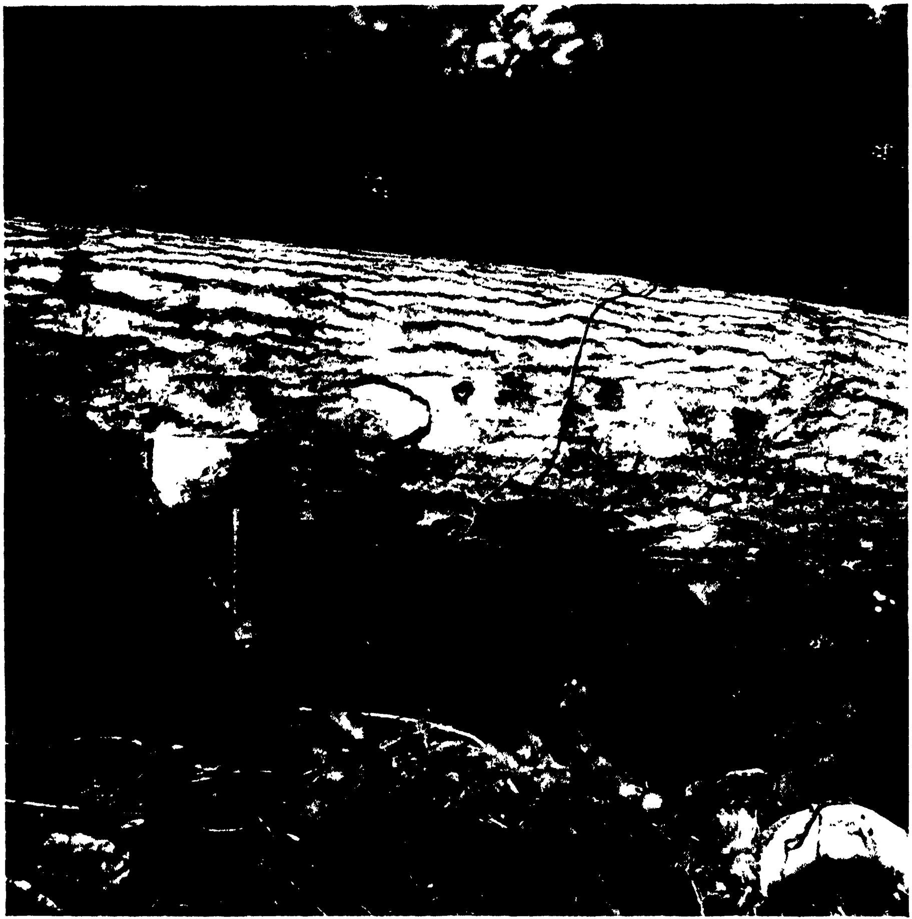

Fig. 35. Aleurites log showing oval lidded door of pupal chamber of longicorn beetle.

the largest of these moths is a noctuid, evidently near the genus *Anua*° (I was unable to secure good specimens for proper identification). Its wood-brown caterpillar attains a length of two inches and is of the semi-looping type. It hides singly or in small groups under the loose bark, its presence there being often indicated by the considerable quantity of frass beneath at the base of the tree. The caterpillar comes out at night to feed upon the leaves. A weak cocoon is formed under the bark which often causes a telltale bulge at that point. The pupa is dark and stout. Hatched or dead pupae of a smaller moth° are often found beneath the bark. Apparently feeding in the layered bark is a small greenish moth° larva with small dark plates on its body (Fig. 36). At the time of my visit most of these caterpillars were in a quiescent state in cocoons in the bark. Some hatched pupae were found in the cocoon chambers which connected with the exterior by means of a little flap door cut out of the bark.

The timber of this tree sometimes shows cylindrical beetle borings.

The blossoms furnish honey for the honey bee and attract many other insects as well as the flying foxes or fruit-eating bats (*Pteropus*).

A host of enemies prey upon these *Melaleuca* insects. Large tachinid flies and ichneumonid wasps (*Ecthromorpha*) attack the larva and pupa of the large moth (*Anua*) (?). This moth may be found entangled in the web of a large spider (*Nephila* sp.) common in the loose niaouli forests; or the moth is to be seen skewered on the thorns of the leguminous shrub, *Acacia farnesiana*. Large centipedes probably feed upon these various caterpillars, while crows are said to frequently shred the bark in searching for the larvae and pupae. The larva of a large elaterid or click beetle was often found beneath the bark sometimes to a height of at least three feet up the trunk, where it no doubt fed upon the various larvae it encountered. The small lepidopterous larva, often so abundant in the bark, was apparently parasitized by two large chalcidid wasps, of which one with a very long ovipositor could frequently be seen exploring the trunks or boring through the bark. Finally, a little wasp of the genus *Sclerodermus* was sometimes seen attacking these small caterpillars among their cocoons.

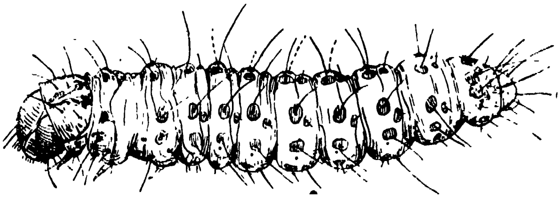

Fig. 36. Niaouli bark caterpillar. Much enlarged.

The honey bee (*Apis mellifera* Linn.) is kept in domestication but is abundant in the wild state, and in my rambles bee trees were continually discovered. Species of banyans (*Ficus*) were frequently thus appropriated. The bee finds pasturage on lantana, casuarina and other plants, but the honey industry is said to depend very largely upon the blossoming of the niaouli. This widespread tree was only in sporadic bloom at the time of my visit, and the farmer-apiarist from whom I desired to purchase honey had hardly any available.

SPIDERS AND OTHER ARTHROPODS:

*Nephila* sp.°: This is a large spider with a pale olive-brown abdomen. It is common in the open *Melaleuca* forests where it spins a strong vertical web that entraps many flying insects, conspicuous among which is the honey bee.

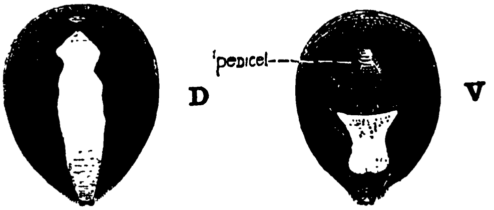

**Fig. 37. Black widow spider (*Latrodectus hasseltii*) abdomen: D, dorsal; V, ventral. Enlarged.**

*Latrodectus hasseltii* Thorell°: This Australasian and Indonesian spider (Fig. 37) is known in Australia as the red-backed, red-striped or jockey spider, and in New Zealand as the katipo. It is widespread and common in the lowlands of New Caledonia, its irregular webs being found on the underhanging sides of boulders and other shelters. On the Isle of Pines it was found in numbers on the base of niaouli (*Melaleuca*) tree trunks, where it was concealed among the loose bark. This spider is related to the black-widow spider (*Latrodectus mactans* [Fabr.]) of America, and appears to be quite as venemous and evidently so recognized by the natives. In addition to the red hour-glass-shaped spot on the underside of the abdomen, there is a broad rather variable stripe on the back or dorsum and that is not characteristic of *L. mactans*. The egg cocoons of both species are very similar.

Some of the literature referring to *Latrodectus hasseltii* follows:

A. Musgrave, *Some poisonous Australian spiders* (Records of the Australian Museum, 16: 33–46, 1927; J. Vellard, *Le venin des araignees* (Monographies de L'Institute Pasteur, 1936; and Berta S. Gerschman and Rita D. Schiapelli, *Revision del genero Latrodectus* Walkenaer, 1805, Reimpresion del Museo Argentino de Ciencias Naturales, 1943).

*Isometrus maculatus* De Geer: This scorpion is a rather small brownish species also found in Hawaii. It occurs under bark and debris and its sting is not regarded as serious. *Hormurus australasiae* Fabr. is a larger and more heavily built dusky species with stout chelae or hands and relatively short tail. It is common under logs and stones in the forest but is not aggressive.

*Scolopendra subspinipes* Leach: This large centipede (millepatte) is also found in Hawaii and in many other Pacific Islands. It was common around Noumea, hiding under objects lying on the ground and under the bark of the niaouli trees. Another species of centipede of rather large size and with the most posterior pair of legs very stout and curved is found in the forest.

# Vegetative Differences Influence the Composition Of Sugar Cane*

By A. H. Cornelison

*The cane and sugar yield differences found to exist, under identical conditions of culture, between the three varieties of cane studied in this experiment are interpreted as being caused more by vegetative time and type responses than by wide absolute differences in photosynthetic and storage capacity differences.*

In view of the fact that our prior studies on the effect of nitrogen on the cane plant (2, 3, 5) were carried out using the variety H 109, it was thought highly advisable to learn how this cane compared in physiological habits with other varieties growing under similar conditions.

In planning the experiment our objective was primarily to obtain information on the genetic characteristics of several varieties, using a "standard" variety with which we were partially familiar for comparison. We were able to obtain three genetically related varieties of commercial plantation standing—H 109, POJ 2878, and 31–1389—that met this requirement nicely. Field weights and census figures; Cuba mill juice samples; glucose, sucrose and total sugars on the dry-cane basis, and certain physico-chemical measurements were to be used to furnish the data for comparisons of physiological habits of the three varieties. They are discussed under their individual titles in this paper so will not be elaborated upon here.

For those interested in the techniques employed, attention is directed to the papers noted in the first paragraph, as the methods employed therein were identical with the ones used in this experiment. The descriptions are too lengthy to repeat here.

## Plan and Experimental Procedure

The experimental area was located on the grounds of the Experiment Station at Makiki. The soil was plowed, harrowed and lined into nine plots, each plot consisting of seven 20-foot by 5-foot lines, each line comprising an area of .002275 acre. The soil in each plot was sampled and tested for available nitrogen, phosphate, and potash prior to planting and all were found reasonably uniform. Seed for the area was obtained from plantations on Oahu and its germination occurred within three weeks of planting.

## Plan

The plan for the test was to run bimonthly harvests from one line of each variety, harvesting all cane in the line. The canes were to be grouped by age of emergence in the field and, in the case of first-appearing "primary" stalks, into chronological age

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* Variety Test No. 1 (Preliminary), Project D-1—Biochemical Laboratory.

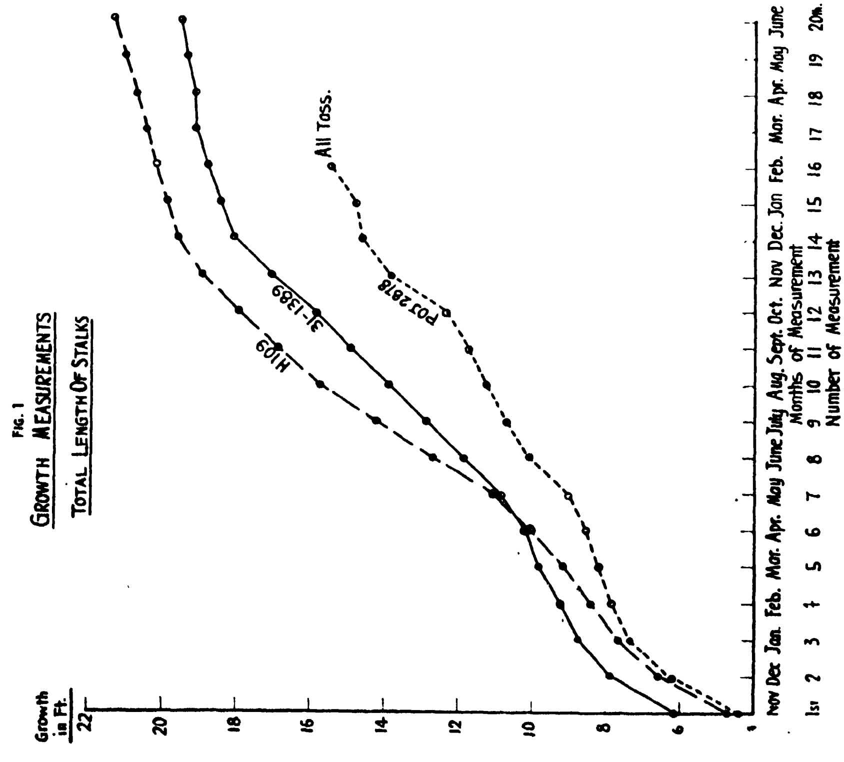


FIG. 1

GROWTH MEASUREMENTS

TOTAL LENGTH OF STALKS

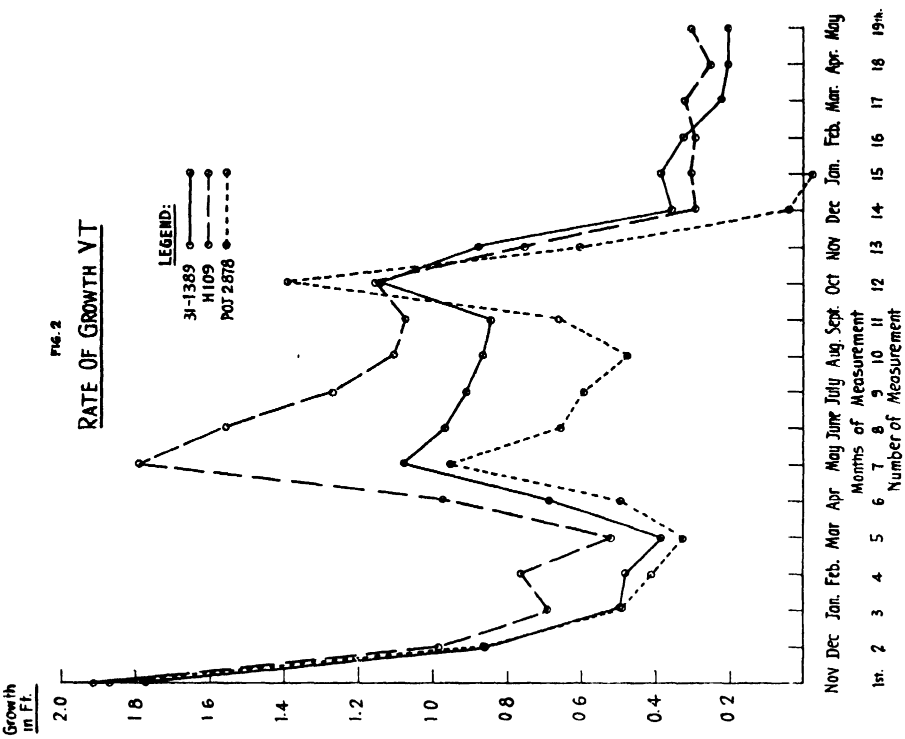


FIG. 2

RATE OF GROWTH VT

sections which were marked with paint, thereby dividing the stalk into four-month seasonally formed groups. Various field measurements, chemical and physico-chemical, and other determinations were to be run on the different samples collected. These diverse determinations will be dealt with in detail later.

### *Agronomy:*

The germination of the seed pieces in this area was poorer than in the fertilizer experiment areas adjacent, partially due to somewhat poorer soil conditions but largely due to non-viable and damaged eyes, especially in variety 31–1389. Replant was necessitated in the plots and for some months these canes were naturally more retarded in development than the original. Before the first fertilization, the area had been thoroughly rogued of all stools affected with mosaic and chlorotic streak, and replanted with healthy, previously germinated seed pieces. The field was generally yellow-green in color prior to the first fertilizer application, but within two weeks it became a normal green and at no time thereafter were there any leaf indications of nutritional disturbances or shortages. (Reference is invited to the title "Nitrogen Content of Cane" later in this paper for discussion regarding this subject.) Eye spot disease appeared in H 109 during the first fall, but none of the other varieties showed any recognizable lesions and the entire area was free of other disease symptoms.

### *Fertilization and Irrigation:*

Irrigation in the amount of 16 inches per month was applied throughout the crop life in the form of two 2-inch irrigations per week. If rainfall of over half an inch was recorded, the irrigation was approximately adjusted to account for it in the schedule. This amount of water is considerably more than is needed to keep the soil above the wilting point at Makiki.

Fertilization of all plots was carried out according to the normal plantation practice of one application at 1½ months, furnishing 50 pounds per acre of nitrogen and 200 pounds per acre of potash and of phosphate, followed by a fall application of 125 pounds per acre of nitrogen; and in March of the following year another application of 75 pounds of nitrogen was applied. The nitrogen was applied from ammonium sulfate, the potash from potassium chloride, and the phosphate from calcium superphosphate. An unavoidable difficulty is faced in undertaking a variety test of this type in that the fertilizer requirements of two of the varieties may be different from those of the standard or optimum for the other variety, thereby unfairly influencing yields of new, unfamiliar varieties.

### *Growth and Stand of Cane:*

Seed pieces for the test were of necessity obtained from different localities on Oahu and in transportation a certain amount of damage to eyes was incurred. In variety 31–1389 many eyes were found to be non-viable and in many cases no eyes were present. (This is an odd circumstance as lack of eyes is normally associated with cane which has started to arrow in the early fall and is not normally found in spring-formed tissue, as pertained in this case.)

Thus, soon after germination, it became obvious that very erratic stands were present in the plots. After replants were inserted and all positive measures were

FIG. 3

Millable 1st Order As Per Cent Of Total Millable

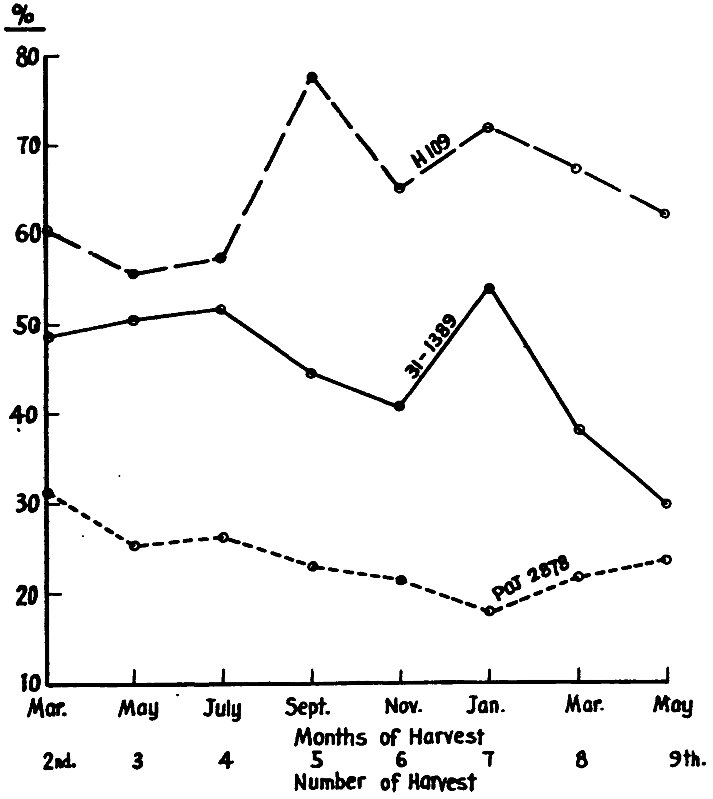
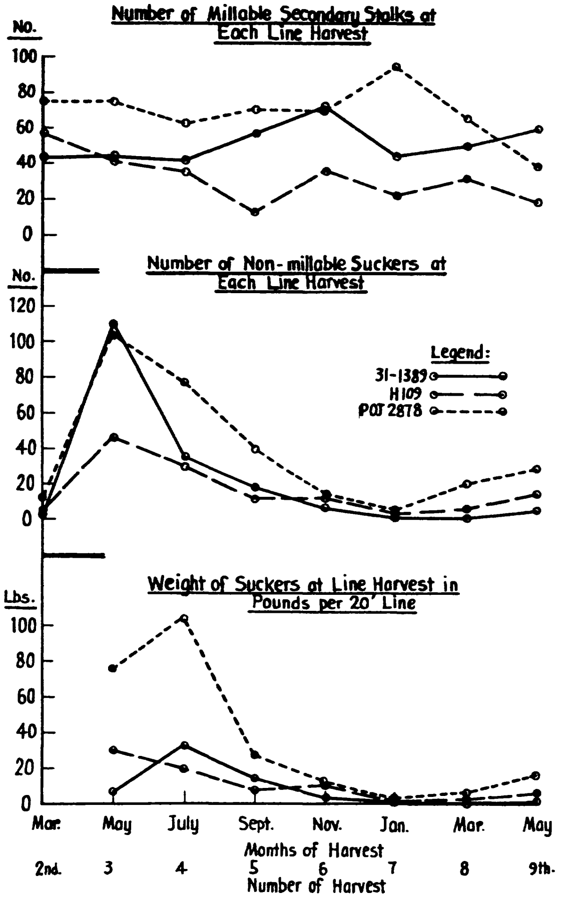


FIG. 4

VARIETY TEST 1


Number of Millable Secondary Stalks at Each Line Harvest

Number of Non-millable Suckers at Each Line Harvest

Weight of Suckers at Line Harvest in Pounds per 20' Line taken to insure uniformity, we judged it expedient to take negative measures to obtain uniform populations in all plots and lines, and did so by excision of shoots so as to arrive at 2.75 shoots per running foot of line (55 per 20-foot line). This figure was derived from final harvest data for the area from a former H 109 crop. We realized we had possibly imposed artificial restrictions on the heavier tillering varieties, but no other method of equalization of the initial disadvantage was apparent. The 55 primary shoots were tagged in each line and will be known henceforth as "first-order stalks" in this report.

All stalks which started at a date four months or later after planting are classified as "secondaries" if they have formed millable cane or "suckers" if at any harvest they were in a non-millable condition or state of growth.

Additionally, the first-order stalks were marked on the node of attachment of the last visible unfurled leaf exposed at the ages of four, and eight months, making two age groups of fixed seasonally formed composition. The parts of the stalk that were in some cases not fully mature (or after eight months not falling into the two aforementioned categories) were classed as "dry leaf," "green leaf," and "non-millable top," as was done in the fertilizer tests. For the collection of data, secondaries were divided into the three latter classifications only, as the heavy stands in the field precluded further work "inside the cane" at the time they arrived at the marking status.

Growth observation was made at frequent intervals and varietal habits were readily identifiable. Both POJ 2878 and 31–1389 made rapid growth and "closed in" about two months ahead of H 109. Also it was soon apparent that POJ 2878 and 31–1389 were both making much greater amounts of millable cane in the first four months than was H 109. As the cooler weather of fall took effect, all three canes slowed down in rate of elongation and a noticeable difference in top type in the varieties became apparent. The top of H 109 was thick, sturdy and well leafed, while both of the other varieties not only suffered shortening of inter-nodes (as did also H 109 to a lesser degree), but the diameter and strength of both were so reduced that winter winds caused more damage to them than in the case of H 109. Tasseling was light in all plots but was greatest in POJ 2878, followed by 31–1389 and H 109 in decreasing order of incidence. When warmer spring weather began to prevail, H 109 with its well-established sturdy top was in better fettle and responded immediately, soon passing the other varieties in rates of elongation and weights of primary stalks. Both POJ 2878 and 31–1389 initiated considerable new sucker growth in this period and, in the case of POJ 2878, senescence of the primary stalks became marked. There was not this large dying back of stalks in 31–1389, as was present in POJ 2878, even though secondaries were initiated at this period. "Going down" occurred in early December in all varieties, but it was especially noticeable that the primaries in 31–1389, either due to stronger root systems or stalk structures, resisted this condition and many remained practically vertical.

By general observations of growth habits, it might be said that POJ 2878 in a 12-month period produces one crop and in the following period produces another crop of secondaries, which in the final harvest at 24 months makes up much the greatest part of the crop harvested. Primaries in POJ 2878 do not carry over well. Contrary to this, 31–1389 appears to be a variety which could be harvested at about

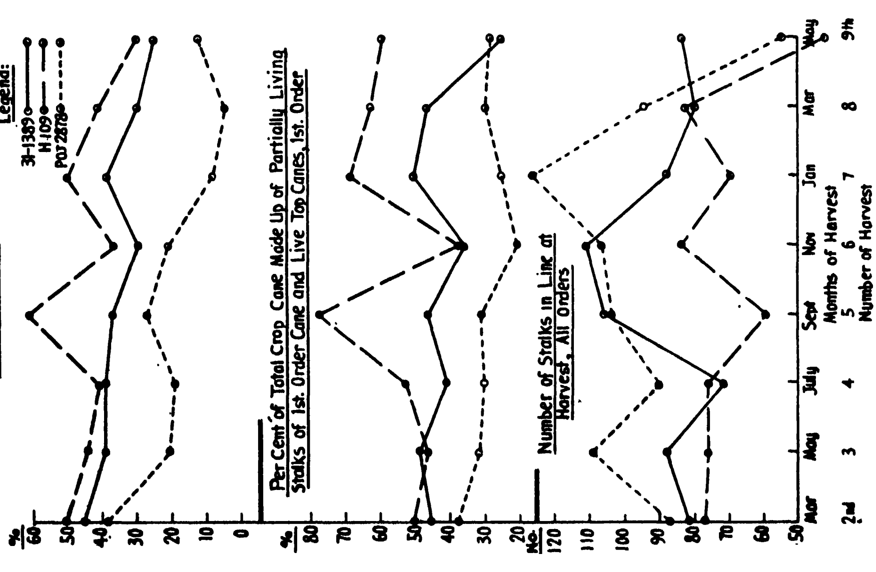


Fig. 5
VARIETY TEST
Per Cent of Total Crop Cane Made Up of Live Top 1st. Order Stalks

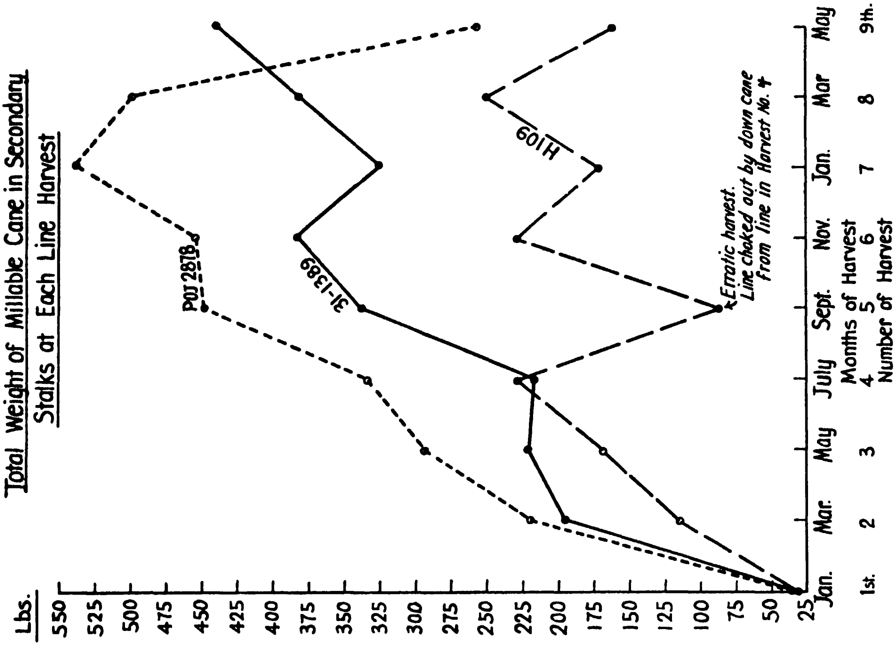


Fig. 6
VARIETY TEST
Total Weight of Millable Cane in Secondary Stalks at Each Line Harvest

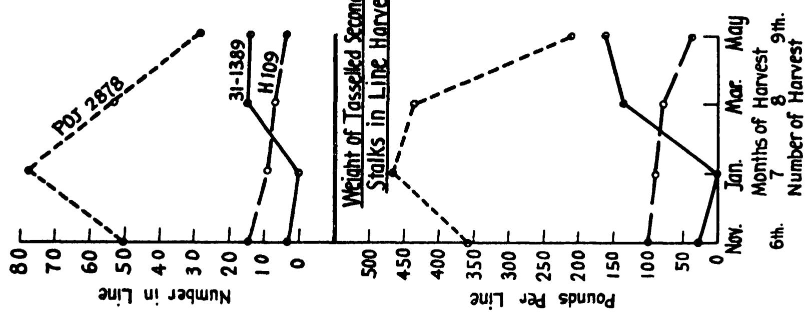


Fig. 7
VARIETY TEST
Number of Tasselled Secondary Stalks in Line Harvests.

12 to 16 months of age or, if not cut then, should be allowed to remain until its secondaries become millable and ripe. These 31–1389 primaries appear to carry over fairly well. In H 109 the crops were made up largely of primaries even at 24 months and large weight increases were made in primary stalks in the second year. These differences in vegetative habits would have a great effect on any composited juice sample taken for comparative studies.

### *Character and Rate of Elongation (Figs. 1 and 2):*

Twenty-five first-order stalks were selected in one interior line of each variety, and monthly total elongation, and rate of elongation measurements, were made on these stalks, the procedure being the same as in the previously reported nitrogen tests. As was noted in the reports on the nitrogen tests, certain errors enter the data, but discussion of these will be omitted here. No measurements were made until the crop was five months old when it was possible to select 25 representative primaries for study. Study of the secondary population was not possible, due to shortage of manpower and time.

At the time of the first measurement, due to the effects of fall and winter weather, the rates of elongation in all varieties were dropping at approximately the same general rates, although there is a rather definite indication that H 109 has a bit lower temperature or light threshold value for growth than the other two, as it holds a slightly higher elongation rate than the other two varieties during the winter. The size of top, noted previously, may have some influence on this, and the findings may be more closely bound up with a physiological age factor for growth than a difference in response to temperature levels. Several variety tests planted at different seasons would probably determine the relative importance of these two factors.

The increasing length of day and temperature of spring caused noticeable increases in growth (elongation rates) in all varieties but were most effective in H 109. The very high rates attained in May are probably attributable to the nitrogen application put on two months earlier, as the May peak rate is followed by a subsidence in rates of all varieties, although temperature and length of day actually increased for a month and a half after the rate peak was reached. Some conclusions on this will be discussed later under the title "Nitrogen Content of Cane." As will be noted from the graphs, growth rates dropped rapidly after December of the second year and we read from this that physiological age has here become the limiting factor.

### *Tillering and Secondary Canes (Figs. 3 to 7):*

Heavy secondary stands were initiated in both POJ 2878 and 31–1389 in May of the second season and were classed as non-millable suckers until about September, at which time most of them had entered the millable secondary class. H 109, by comparison, started less than half as many suckers or tillers as did the other two canes and, by the onset of winter, a large proportion of these were fairly mature canes in vegetative appearance, although poorer in juice quality than the primary stalks.

Although all varieties were eventually started with uniform stands, POJ 2878 developed a larger number of sticks per foot of line than did the other two, and an inspection of Figs. 3, 4, and 5 will show that for a considerable period of the second

FIG. 8

Total Weight Of Millable Cane (Green)

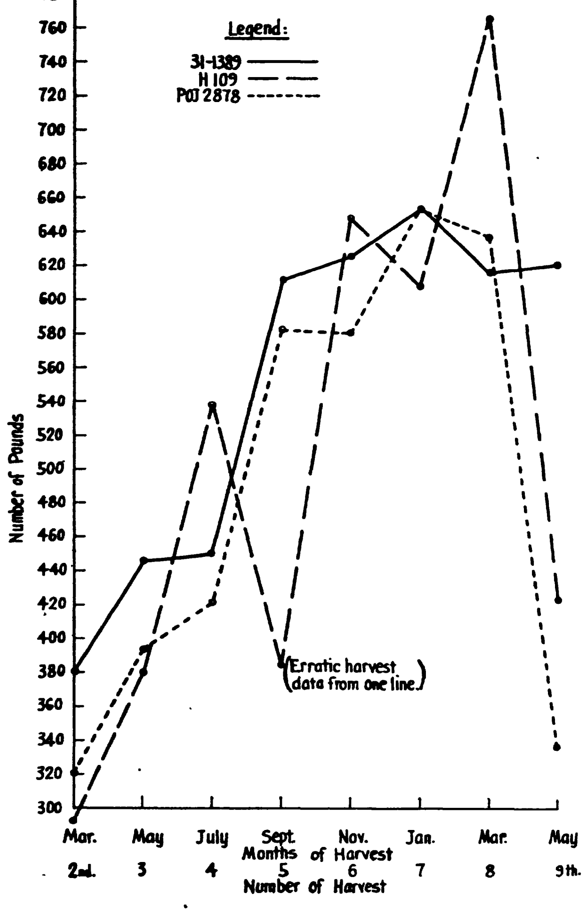
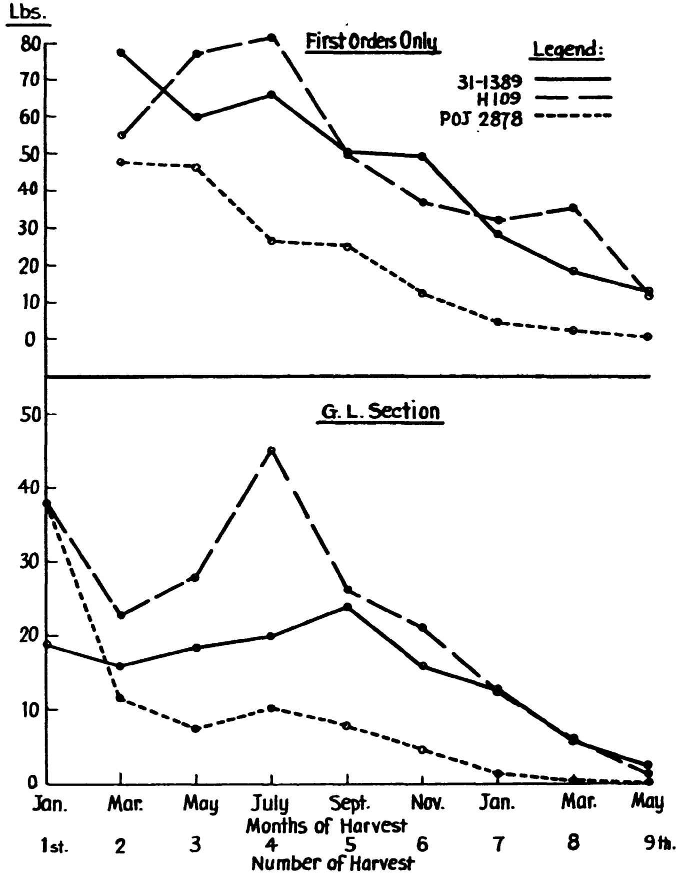


FIG. 9

Green Weight At Harvest

Non-millable Top Section



season less than 30 per cent by number of the POJ 2878 crop in the field consisted of primaries. In 31–1389 during the second season the crop is roughly half and half, primaries and secondaries, while H 109 is, as usual, made up of about 65 per cent primaries, similar to results obtained in our former work.

We fully recognized the possibility that our excision of shoots for equalization of stands may have forced the heavy stooling varieties to send up the larger proportions of secondaries and, in a more comprehensive test following this preliminary one, allowance was made for such a condition to evidence itself if present.

An odd characteristic of POJ 2878 was the very large proportion of tasseling which took place in the less-than-year-old secondaries. From the results of our fertilizer experiments, it appears quite possible that this heavy secondary tasseling was induced by a shortage of available nitrogen for normal growth of these secondaries under the single second-season application used in this experiment. The nitrogen content of the secondaries was unfortunately not determined. This tasseling was followed within three months by the dying back and spoiling of a large percentage of the stalks so affected. An interesting fact appeared in July of the second season in 31–1389 and that was the gradual disappearance of small suckers through dying back. They did not enter the crop as millable stalks.

### *Total Weight of Cane (Fig. 8):*
### *Weight of Cane in Age Sections (Figs. 9 to 13):*

The curves for total weights of millable cane for all ages of stalks shown in Fig. 8 are subject to the criticism of being taken from one 20-foot line harvest and while, on the whole, quite representative of conditions in the field, they are subject to the errors of non-replicated plots. This shows up quite definitely in the erratic behavior of H 109 in the September harvest (No. 5) and in this case was due to shading out, *i.e.*, the border effect of the line cut in harvest No. 4 which had "gone down" over No. 5. This one harvest yield should have shown weights equal to, or slightly above, those for 31–1389 and POJ 2878 in the curves.

The entrance of many formerly non-millable second-season secondaries into the millable cane class in 31–1389 and POJ 2878 at this harvest (No. 5) raised the yields of cane greatly, whereas weight increases in H 109 were largely made in the primary class of stalk, thus making the stand in H 109 much more homogeneous as to age and yield characteristics.

In Figs. 9 to 13 are shown the yields from the age-season sections of the primary stalks. They are presented on both the green- and dry-weight bases of calculation.

In the 4-month age section the slow-starting qualities of H 109 are clearly indicated (Figs. 1 and 8). The position of POJ 2878, as the lowest producer in this age group, was due to its smaller, lighter stalk characteristics and possibly reflects the effect of our having limited stalks per line to a common count in all varieties. Also it is illustrative of the fact that elongation rates were less in this variety from an early age.

In the 8-month section H 109 had obtained a foothold and had begun to produce primary stalk weight at higher rates than the other two varieties, a fact not shown by elongation rates or total elongation (Figs. 1 and 2). The weights in this section

FIG. 10

Green Weight Of Cane At Harvest

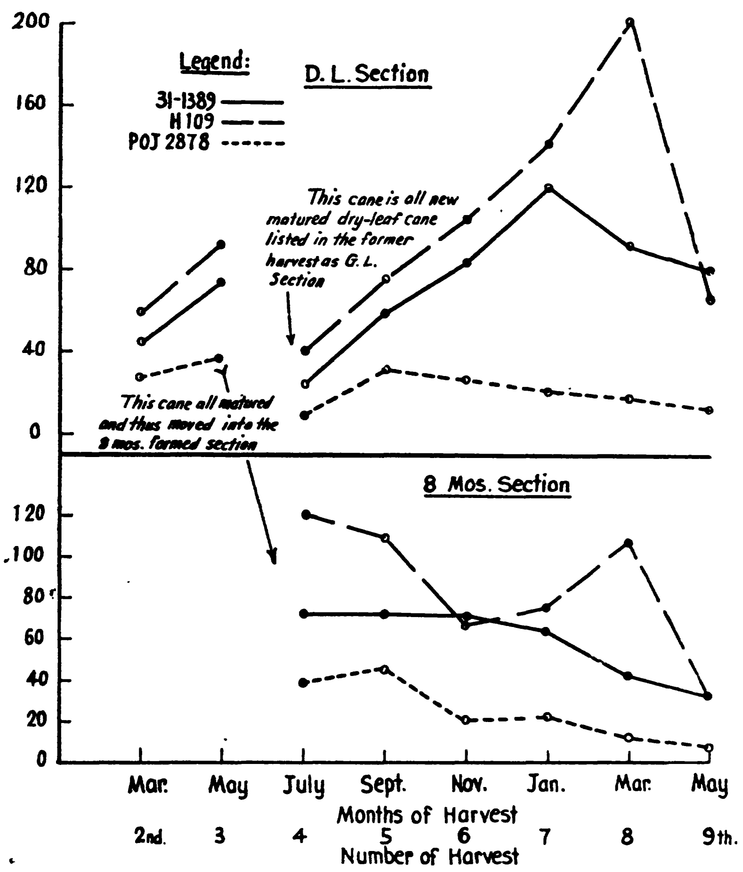
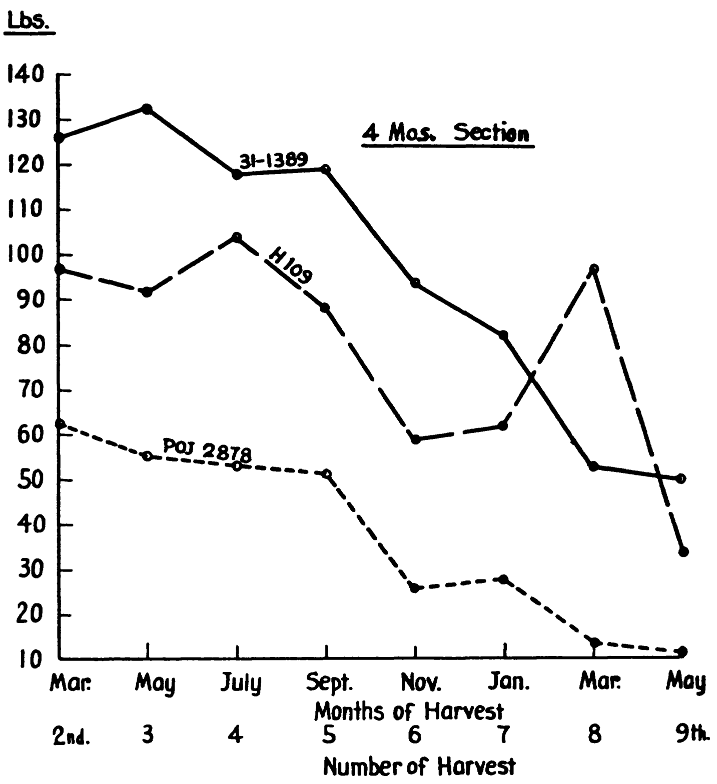


FIG. 11

Green Weight Of Cane At Harvest



are also indicative that the fall temperatures, under which this section was formed, did not inhibit the weight growth of H 109 as seriously as it did the other varieties. These weights appear to indicate also that H 109 possibly has a lower threshold value for growth-temperature relations than have the other two varieties. If so, then the assumed 70° F. base for "day-degrees" calculations may not be fixed and may have a different value for each variety. In the elongation rate and total elongation curves, Figs. 1 and 2, the discrepancy between length growth and weight growth is strongly pointed out by the fact that H 109 did not move into the lead in the elongation measurements until long after this 8-month section was complete and in the dry-leaf stage of growth, although H 109 was definitely in the lead, in weights produced, early in the fall, as will be seen from the data for both dry-leaf, green-leaf, and 8-month sections in Figs. 9 and 10. (Refer to description of the physiological composition of these samples, pages 149 and 151.

The dry-leaf section after the fourth harvest represents the mature cane formed after the completion of the 8-month section and shows the weight increments added from harvest to harvest. In this section total elongation and elongation rates of H 109 and 31–1389 correlate much more closely with cane weights produced at this age than in the former 8-month section just discussed; this is perhaps indicative of a change in H 109 in the relative stalk dimension ratios of mean length to mean diameter (or in density of the stalk).

In the green-leaf section the weights are made up of almost entirely new tissue at each harvest and show the amounts of cane produced under seasonal influences. The close parallelism of this section to the rates of growth curves, Fig. 2, for H 109 and 31–1389 is evident. However, in the case of POJ 2878 the rate-of-growth curve, for the live active primary stalks which are measured, does not correspond to total cane weights in the field, since losses, due to the death of the other primaries, had more than offset the additional growth made by the few remaining healthy stalks in this variety.

The non-millable top section is made up of non-colored, soft, white, top in which elongation of internodes has been only partially completed. This section of cane is the section of stalk which formerly was topped off and discarded when we were able to cut cane by hand. The weights involved in it are not representative of length-growth rates or of rates of weight formation; they do, however, indicate from harvest to harvest the decreases in relative weights and volumes of vegetative material making up the active apex or growing top with increasing age.

The summation of the weights of the non-millable top and green-leaf section at any harvest is the weight translation of the elongation rates shown in Fig. 2.

When we take into consideration the variable behavior of the primary stalks of these varieties, as influenced by age and season, and the simultaneous behavior of the secondary and sucker fractions as depicted in Figs. 4, 5, 6 and 7, the tremendous complexity of sampling a field of cane at any time can be comprehended. Regarding the practical application of sampling for control of fertilization in the field, we have found by experience that with our present varieties and cultivation practices, our fertilizer applications must be applied inside of one year of age (from planting or ratooning). If we control the fertilization applied by crop index figures derived from primary stalk samples within this first-year period, an inspection of Figs. 4,

FIG. 13

Dry Weight of Cane At Harvest (Lbs.)

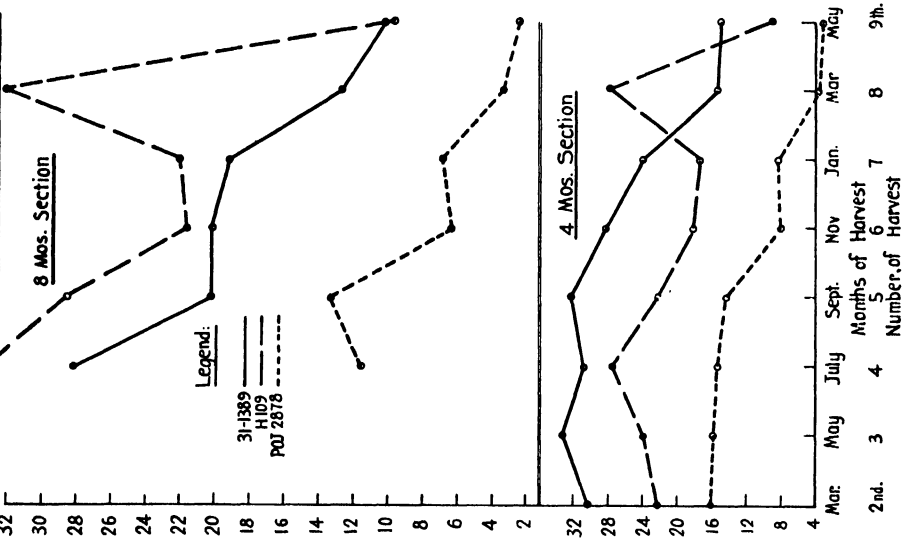
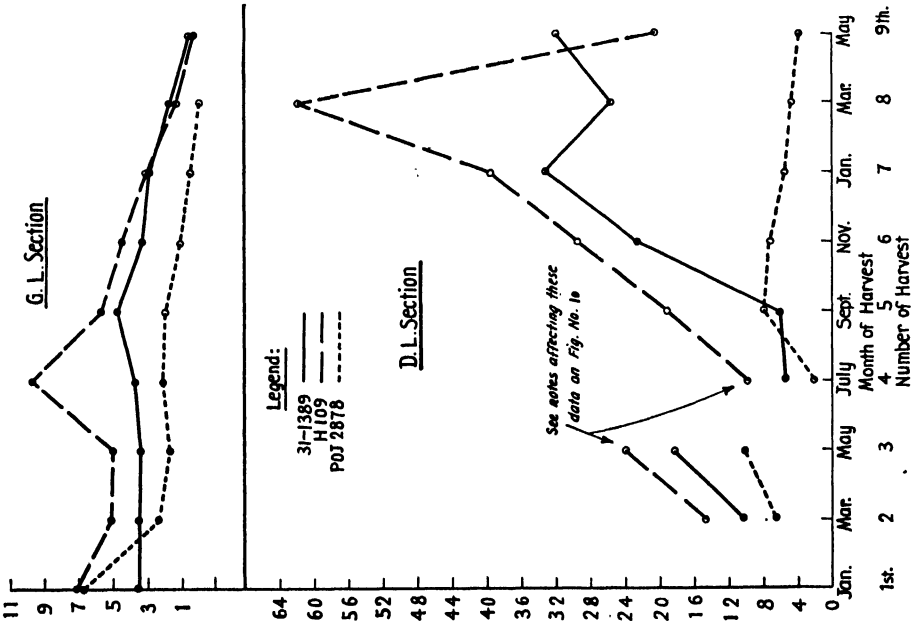


FIG. 12

Dry Weight Of Cane At Harvest (Lbs.)



5, 6 and 7 will show that the 30 to 60 per cent of the final crop made up of the secondaries, depending on the variety involved, will not only not be represented in our index samples, but will not even be existent in the field, except possibly as less than one-foot suckers. Index figures, based on primary stalks from short crops and on crops of low-tillering varieties (where only primary stalks will be involved in the stand) may possibly be used satisfactorily for control of fertilization. However, the shortage of manpower, high costs of cultivation of short crops, and other economic factors have practically necessitated that most of our plantations adopt long-crop practices, and nearly all of our better recent cane varieties are vigorous-growing, heavy secondary-stooling types in which homogeneous stands do not exist except at a very early age.

The factors effective in producing secondary growth, and the physiological behavior of this secondary growth, have not been worked out. We are cognizant that light incidence, timing of nitrogen fertilization, initial stand density, temperature and other variables have a bearing on the number of secondaries produced. The subject has not been studied quantitatively or qualitatively, however, to the extent where we are able to predict varietal conduct of these secondary stalks.

Hence until a complete study has been made of a variety and we are able to predict more accurately exactly what the yield of secondary and other stalks is most likely to be under any set of growth conditions and fertilizer treatments, the selection of a so-called "representative" sample, taken within the first year of life of a crop, cannot reliably approximate representation of what the crop will be twelve, ten or even six months in the future. The analysis of such a sample and the interpretation of the analytical data will offer little help in the guidance of fertilization of stalks which were non-existant at the time of sampling.

### *Mortality (Fig. 5):*

Death of first-order stalks in all varieties had set in before the spring of the second year. Mortality rates which were greatest for POJ 2878 were followed roughly in decreasing order by 31–1389 and H 109. Some of these stalks died due to tasseling in the first fall, some due to tops being broken by wind, and some were broken or split at "going-down" time in the first winter; others, parallel to our findings in the fertilizer test, died for no readily apparent reason.

In secondary stalks, dying out of weak shoots through overcrowding at secondary closing-in time occurred in all varieties. This factor, however, was more operative in POJ 2878, as it initially had many more secondaries than the other two varieties. Tasseling in this variety, as mentioned before, was heavy in the second fall and the affected sticks died back rapidly soon after. In 31–1389 there were very few secondaries that tasseled in the second fall.

### *pH of Cuba Mill Expressed Juice (Figs. 14 and 15):*

Juice acidity of the three varieties, as determined by the Beckman pH meter, shows not only the same general levels of pH as found in former work (2, 3), but also the same seasonal and age trends in the age sections studied.

The higher acidity of the non-millable top sections is probably ascribed to the increase in concentrations of organic acids concomitant with vegetative activity. In

FIG. 14

pH Of Expressed Juice

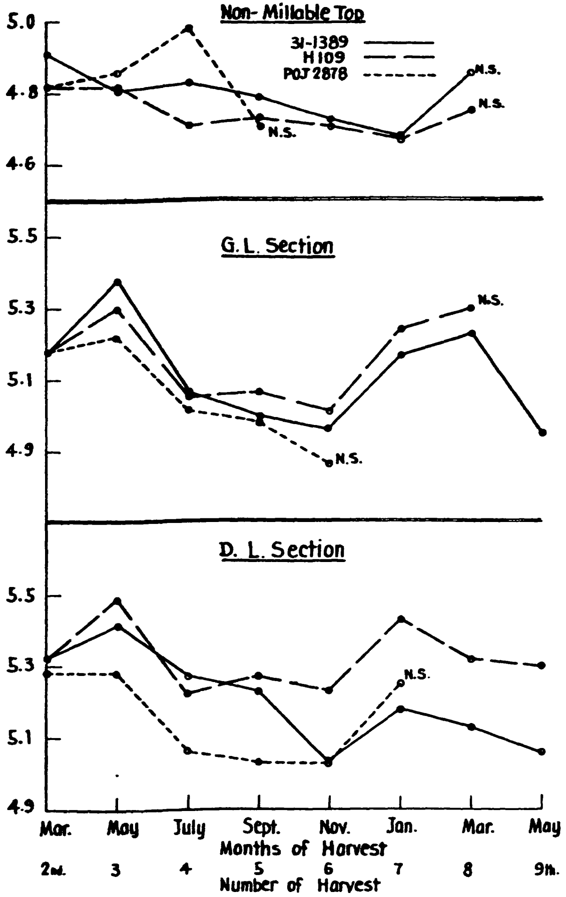
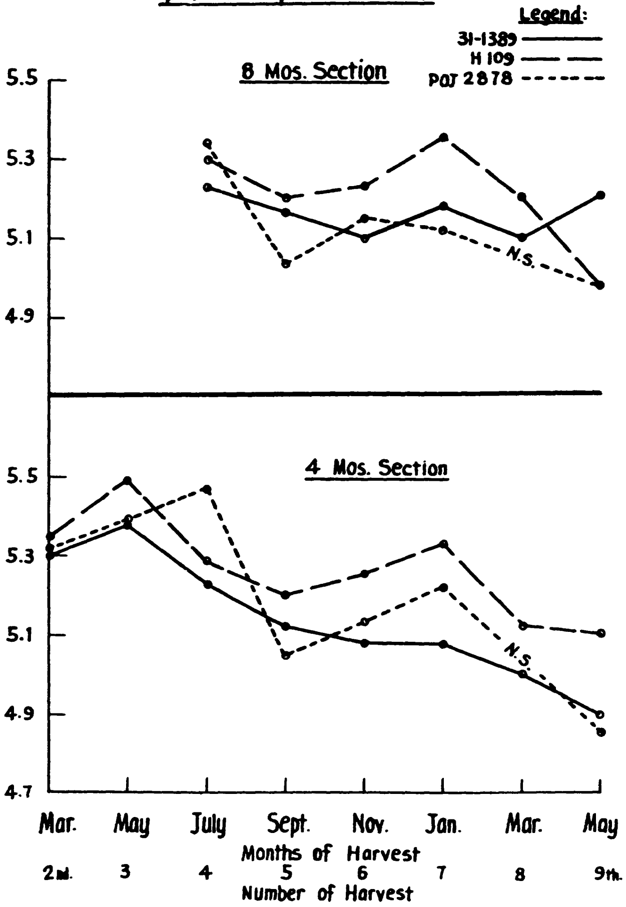


FIG. 15

pH Of Expressed Juice



the green-leaf sections lower acidity is found, probably due to diluting effects attendant to further cell development, such as reduction in pectic acid, tannic acid derivatives, and condensation of amino acids to proteins. One must remember also that in the green-leaf stage of development, anabolic processes far out value the catabolic, and that organic acids formed by respiration in the cells have not had time to accumulate as they will have done when this tissue becomes mature cane (as in the 4-month section).

Identification of the various acids in the sugar cane plant has not been made. This field could quite profitably be followed since a study of our former experiments will show that increased age is accompanied by decreases in pH in mature cane until a pH of 4.8 to 4.9 is reached, at which time degeneration of the crop sets in. We feel that this degeneration is probably due in a large part to increased destructive activity of invertase (or other enzymes) at or about this pH.

Microchemical pH range indicator studies on tissue cut from age sections having juice acidities of 4.8 to 4.9 showed that there were interfaces in the protoplasm of some parenchymous (storage) cells with pH's of 3.2.

A factor which we recognize as being active in the seasonal pH variations is the change in water content of the plant parts with possibly no quantitative change in total acidic material present. In a prior report (3, p. 171, second paragraph), we were led to doubt the validity of conductivity measurements on sugar cane saps when interpreted as a measure of the ash constituents (usual physico-chemical interpretation), and we suggested that more likely they were a measure of the acidic radicals in the saps. A comparison of pH and conductivity curves in this experiment will, we feel, further bear out our contentions in the matter, although the relationship is not perfect.

It will be noted that at the seasonal periods of higher acidity and conductivity of the saps of the various older sections, there was an accompanying increase in moisture. From these conditions it may be inferred that there was a real increase in the acidic contents of the expressed saps, a higher ionization of acidic materials, or a change in the chemical composition of the acidic materials themselves.

While our general statements still hold true, in the latter part of the life of the older age sections of the stalk some other factor or factors are operative for each variety, for the relative conductivity curve positions (Figs. 16 and 17) found in POJ 2878 and 31-1389 do not correspond to those of the pH determination. While purely speculative, since we did not run ash analyses on this tissue, we feel that the results are possibly due to small variable salt concentrations in the older tissues.

The pH of juice expressed in the Cuba mill was, we realized, the result obtained from a composite of true solutions, suspensions, and colloidal sols and, as such, represented no one thing. Attempts to find in living tissue, as mentioned above and in a former paper (3, p. 174) just what the pH of vacuolar saps were, by means of range indicator dyes, met with no success through protoplasmic interface interference with dye penetration. We still do not know at what acidity value sugar is held in storage cells. All indications are that the vacuolar saps of storage cells are acid but one must not construe pH of expressed juice to be identical therewith. Water from the vascular system, salts in transit, liquids from cell walls and protoplasm,

FIG. 16

Electrical Conductivity Of Expressed Juice In Mhos

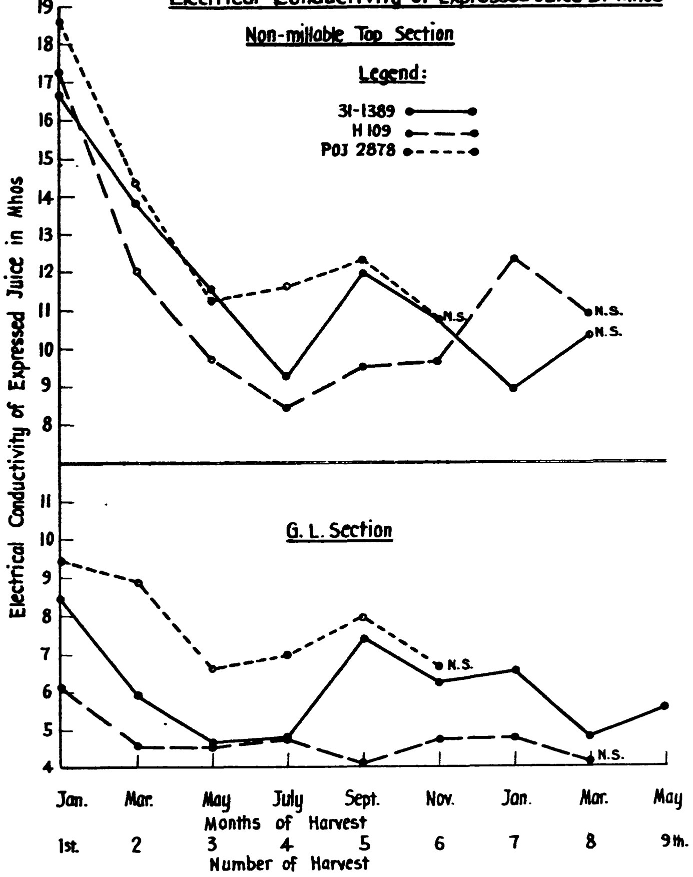
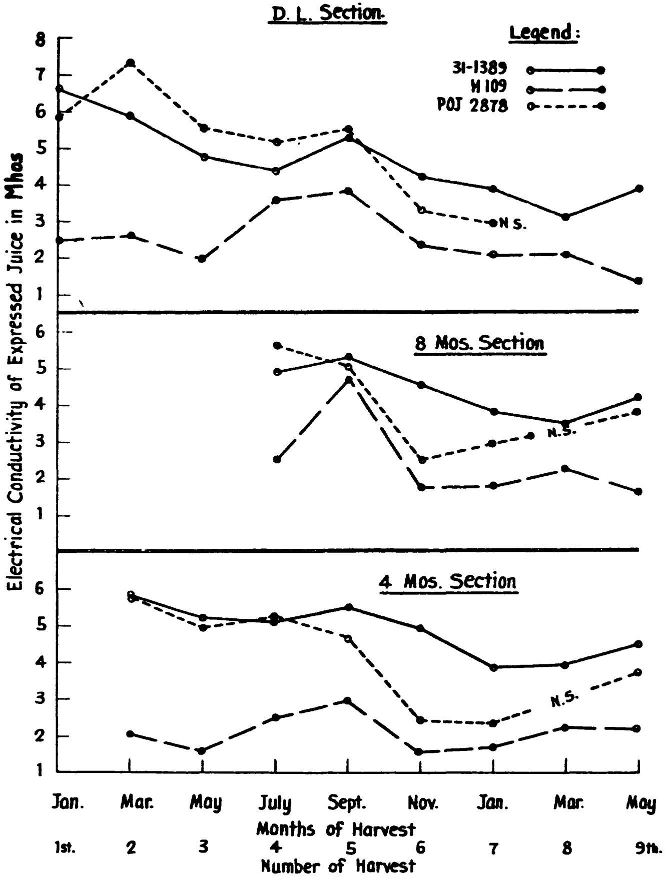


FIG. 17

Electrical Conductivity Of Expressed Juice



all are mixed indiscriminately. To the sugar boiler, who is liming for clarification, the figures are valuable, but they leave much to be desired by the plant physiologist.

From a study of Figs. 14 and 15 it becomes immediately apparent that H 109 has a higher pH (or less acidity) of juice than the other two varieties, except in the non-millable top section. This condition also seems to be borne out by the conductivity of juice (Figs. 16 and 17), for therein this variety shows considerably less carrying power for electrical charges than do the other two varieties.

At this time we can offer only a presumption as an explanation of why these acidity differences occur or what they are actuated by, since we did not identify the acidic materials.

On the thesis of accumulation of organic acids with increases in physiological age and decreases in physiological activity of the cells, we might expect some such result since H 109 maintained its vigor in primary stalks longer than did the other varieties. However, we are not satisfied that this is the real reason for difference, for we observed at each line harvest that both POJ 2878 and 31–1389 stalks, when cut and exposed to the air, seemed to form brown oxidation products much faster than did H 109 cut sections. This browning of cut surfaces has been ascribed to presence of tannic acid and/or tannin derivatives. Since no explanation of how or why tannins occur in plants has been made by plant physiologists, although all kinds of unproved theories have been offered, we will in passing merely note their presence as varietal differences.

While not having a direct bearing on this test, we would like to direct attention at this time to the fact that on several occasions we have found levo-rotatory sugars in excess of dextro-rotatory in the reducing sugar fractions in the expressed juices of cane. This condition occurred in every case during very warm summer weather and in rapid elongation or cellulosic tissue-formation periods. While purely hypothetical, we felt that their presence might be indicative that in the metabolism of the cane cell, glucose was preferentially used to form cellulosic materials and levulose used for furnishing the cell energy. If this were a fact, we would expect to find glycollic acid and a-hydroxy-butyric acid formed during the breakdown of the levulose. To date we have been unable to find methods to isolate these acids from mixtures in the plant and so are unable to report any progress. Conant (1) reports the presence of glycollic acids in sugar cane, but we have been unable to find his source material for reference. Due to apparently less "fiber" being formed in both 31–1389 and POJ 2878 than in H 109, it may be possible that more carbohydrate-derived acids, from the reducing sugars used in cell metabolism, are left behind in these two canes than in H 109. We would like to have these points watched for by other workers as they may be able to establish relationships we can only hypothesize.

### *Conductivity of Juice (Figs. 16 and 17):*

We ran conductivity measurements of expressed juice because we originally had accepted the idea that conductivity of saps measured soluble inorganic ash constituents in the plant. Today we are more than dubious of this idea. The data accumulated are, we now feel, of little value in themselves, but when studied in relation to pH and moisture data, they have been of help in aiding us to interpret the latter a bit more intelligently. We present the plotted results herewith but wish to make no

FIG. 18

Gms. $H_2O$ Per Gm. Of. D. M.

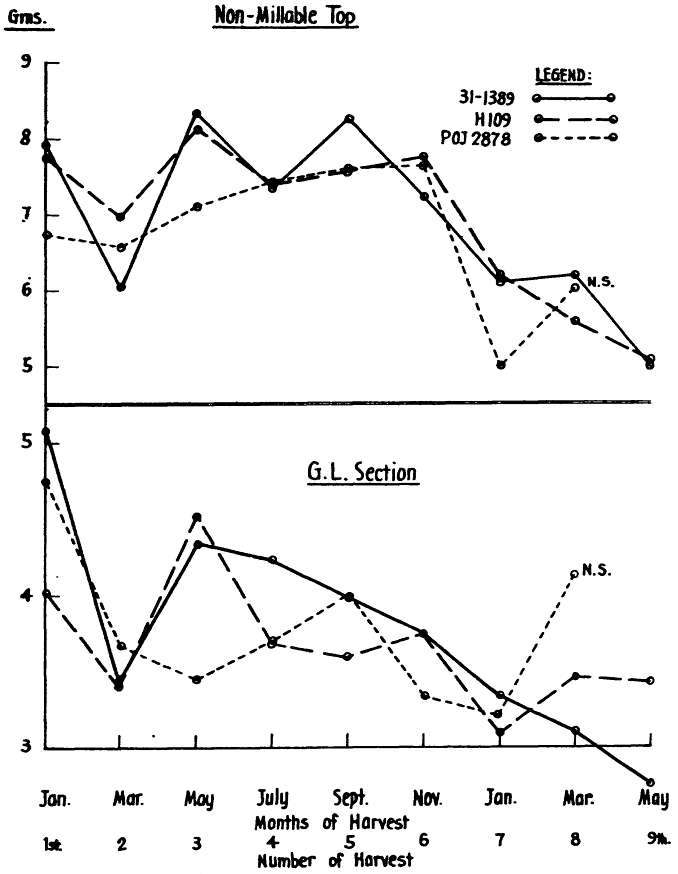
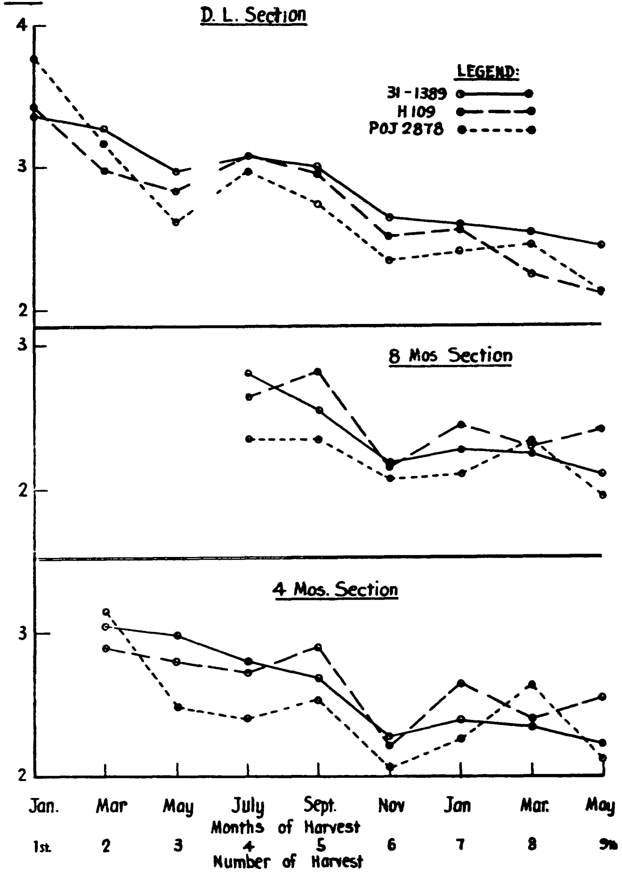


FIG 19

Gms. $H_2O$ Per Gm Of D M.



further evaluation of them since they are approximately the inverse of the curves for pH just discussed.

*Moisture Content of Cane (Figs. 18 and 19):*

The water content of the canes involved in this study is expressed in two ways, one as grams of water associated with one gram of dry matter, and the other as per cent of dry matter in green matter.

Of primary interest is the fact that POJ 2878 rather consistently has a lower water content than the other two varieties at all chronological ages studied and in all age classes of cane. In general no such difference appears to exist between H 109 and 31–1389, harvest by harvest: however, after careful study we do feel that while there is no great final difference in inherent moisture levels of any set of age-section tissues, there are different moisture levels for each variety which are determined by the magnitude of seasonal vegetative activity.

The question may arise in the reader's mind as to why the hydration curves, especially for H 109 and 31–1389, cross and recross in any age section as they do. We offer no apology for we know the determinations were mechanically correct, but we do offer the explanation, for the sake of clearness that many factors affect such samples. One factor is the normal variability which may be expected when dealing with as nearly identical biological material as can be chosen. As most cane men know, this error can hardly be reduced below ± 2 to 3 per cent in field-grown cane even under the best of conditions.

As is recognized by many biochemists, absolute water content figures from living tissue are impossible of attainment, although highly useful relative measurements are easy to secure. The higher the colloid content of tissue, the more inaccurate become the relative moisture determinations by oven, vacuum oven, evaporation, etc. Our methods were standardized throughout this experiment and constant weights of samples were attained for our conditions of oven drying at 85° C. in every case.

Another variable was traced to actual percentage differences anatomically in the tissues making up the samples. With nodal and internodal tissue mixed in the age-section samples, there were considerable differences introduced due to the difference in length of internodal tissue (and volume) as compared with nodal material. An experiment to follow this one has been designed to take into consideration this anatomical factor and our findings will be reported at a later date. Great varietal difference in length of internode exists as all cane operators have observed. In our former work, and from other investigator's data in the files of the Experiment Station on rates of leaf appearance, we find that rates of node formation are relatively constant, whereas the length of tissue laid down between the nodes is dependent upon growth conditions existent at the time the internode developed.

The last and most confusing factor in moisture determinations on cane is our inability to evaluate water which is not strictly speaking involved in the life processes of the cell. In this category falls the water in the open vascular system of the plant. The amount of this water varies largely with available soil moisture, will drain freely from cut stalks or will squirt out in fine streams as the cane first enters the crusher in the mill. It appears to be present much in excess of the needs of the plant for cell turgidity or transpiration. Technically speaking it will interfere with accurate, relative moisture determinations unless irrigation and rainfall are posi-

FIG. 20

Percentage Reducing Sugars In Juice

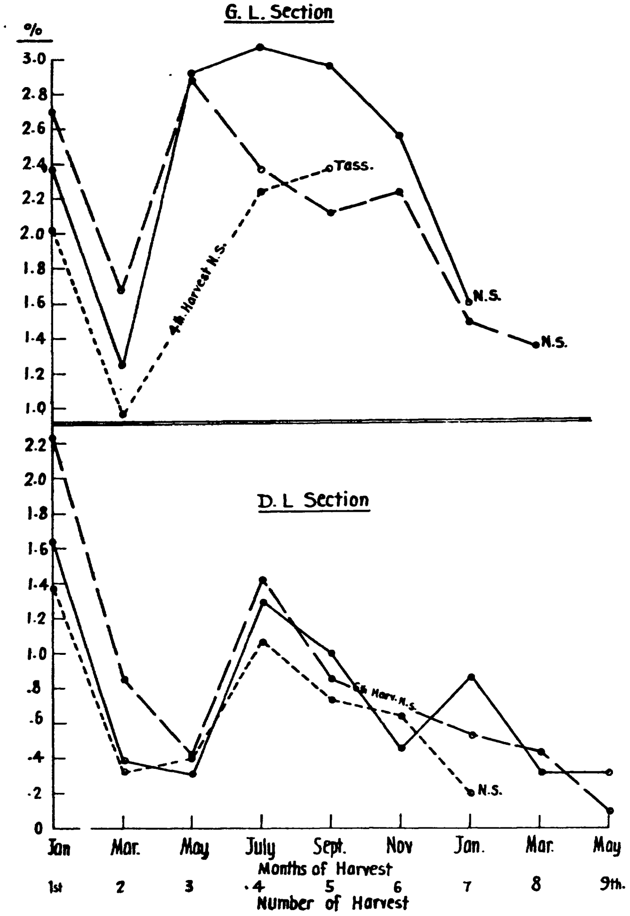
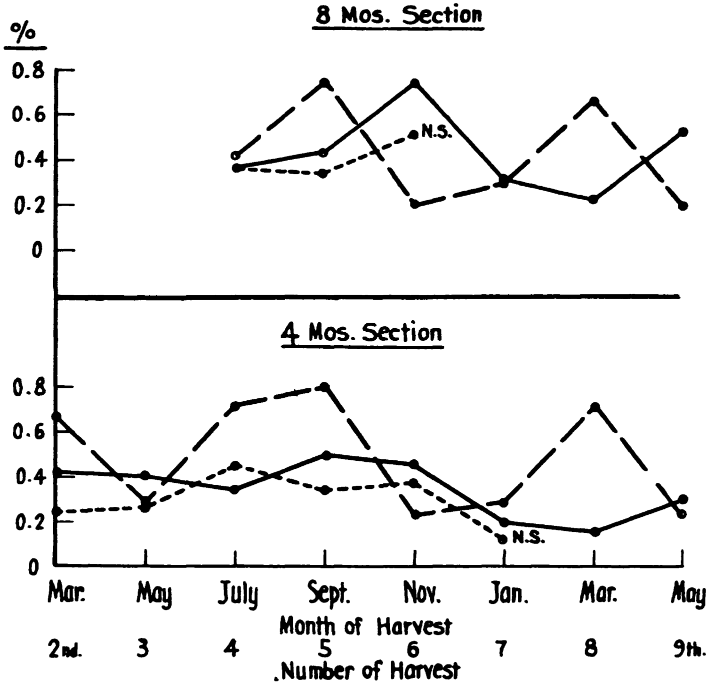


FIG. 21

Percentage Reducing Sugars In Juice



tively controlled. We tried to avoid this type of moisture variation by keeping the cane lines thoroughly irrigated at all times and the vascular system flooded. The rapid increase in dry matter of the top section at the seventh harvest is directly attributable to the increase in volume of nodal material in the samples due to season and age interferences with elongation of internodes.

*Reducing Sugars (Figs. 20 to 24):*

Reducing sugars were determined on the dry-weight basis and on Cuba mill expressed juice. While trends due to season, age, and vegetative activity are comparable in the various curves, a certain degree of nonconformity exists in the position of the varieties at various harvests. At first glance these nonconformities appeared to be inaccuracies in analysis and we were almost led into blaming extraction variations in the Cuba mill. The regularity of the reducing sugars on dry-weight basis in the older parts of the stalk for the sixth and seventh harvests would seem to indicate such inaccuracies existed. A careful study of the sucrose figures both in juice and on dry-weight basis, and of moisture, showed that the sucrose had suffered a decrease, thereby reducing the base of absolute amounts of dry matter used in percentage calculations. Thus for the reducing sugars on dry-weight basis to remain at an approximately constant percentage figure (as they did), they too must have suffered a reduction in absolute amount, as was indicated in the juice analysis figures.

Here again is proof of the seasonal ebb and flow in sugar content of older tissues for, had the indicated reduction in both sucrose and reducing sugars been used by the plant for formation of only fibrous cellulosic materials, the reducing sugars on a dry-weight basis would have shown a depression. However one analyzes the data, either loss through translocation or catabolism was operative in the sixth and seventh harvests in H 109. Since tillering was not taking place at this season and age of crop, metabolic losses are indicated.

Once again we feel we have evidence that the sugars of the cane plant are not "static" once they have been laid down, but are dynamic and changeable under the influence of season, weather, and age.

The three varieties all show trends due to season and age similar to those found in our former experiments. H 109 due to its vegetative vigor in the second season has a higher reducing sugar content in the older age sections, this, however, does not appear to be much higher at the last harvest than the other two. In the curves for reducing sugars on a dry-weight basis, it will be noted that both POJ 2878 and 31–1389 in the four- and eight-month sections reached a minimum level at the fifth harvest (September), while top, green-leaf and dry-leaf sections were still immature in this respect. Since the most rapid primary cane formation was made in the first year in these varieties and falls into the two categories which were more mature in quality, it appears that they could be harvested with fair results at 16 months of age and again at about 22 to 24 months when the entire surviving stalk stands have reached maturity throughout.

POJ 2878 first-order stalks play proportionately so small a part in the crop *after 12 months* that too great value should not be placed on these analytical results in judging optimum harvest periods. However, the data for 31–1389 and H 109 are pertinent, as larger proportions of the crop are first-order stalks.

FIG.22

Percentage Reducing Sugars On D. M.

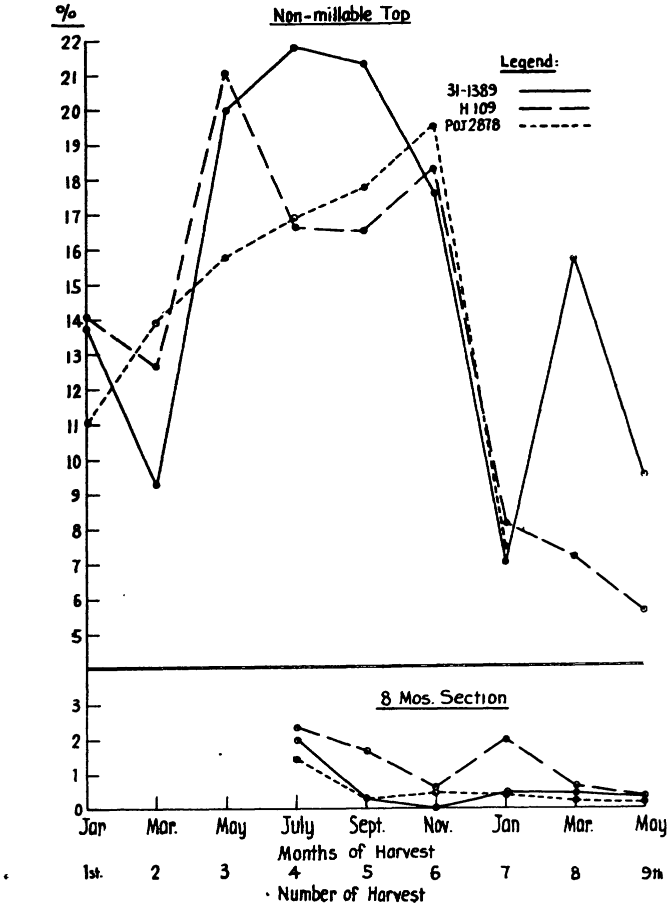
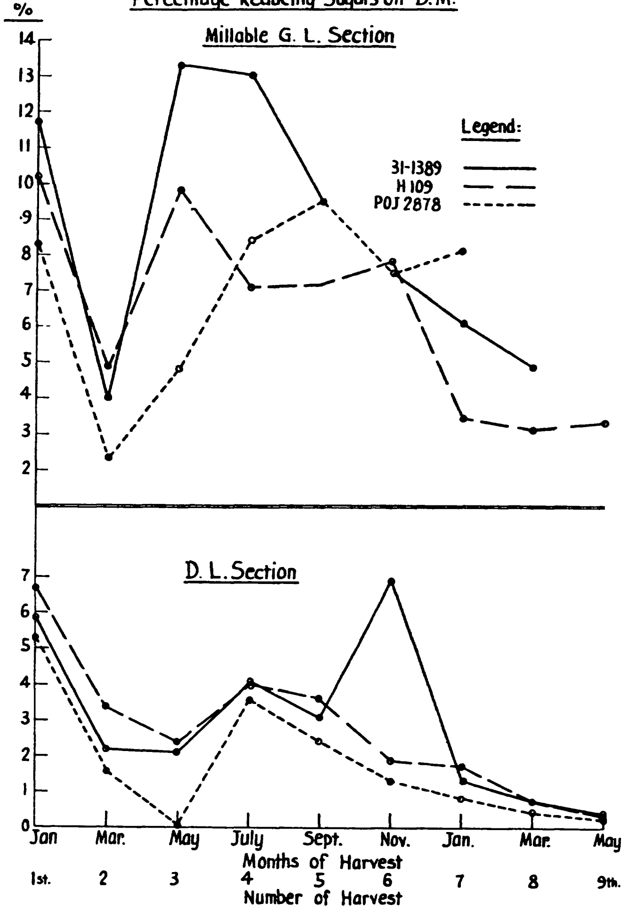


FIG 23

Percentage Reducing Sugars On D.M.



Once again, as in our former work, the increases and decreases in percentage of total sugars, due to seasonal effects, are operative; the gains and losses in sucrose are greater by several times than the corresponding contemporary variations in reducing sugars; and the water content of the tissue varies with the reducing sugar content. However, somewhat contrary to our former experience and affecting all three of the varieties alike, we find sucrose content depressed at the same time the water content was depressed. This occurred during the fall harvests of the second year (November and January). The only explanation presenting itself for this condition is that considerable non-sugar dry matter was formed under the fall weather stimulus and was built at the temporary expense of stored sugars. The deficits encountered were apparently made up in the spring months following. No such condition was encountered in the contemporary fertilizer experiment adjacent, leaving us at a loss to explain this satisfactorily.

*Sucrose (Figs. 25 to 29):*

The sucrose is expressed in two ways, as were the reducing sugars, on the dry-weight basis and on Cuba mill expressed juice. Comparison of the curves for the two bases of expression show considerable dissimilarity, not only in position of the varieties at each harvest but in the general seasonal trends as well.

Per cent of sucrose in the juice is highest in POJ 2878 in the two mature-age sections (four- and eight-month) after the canes were one year of age, and on the dry-weight basis a similar condition seems to obtain. However, on the dry-weight basis of the dry-leaf, green-leaf, and non-millable top sections, POJ 2878 is lowest in sucrose content (after one year of age). This apparently contradictory state of affairs is due to the reduced water content of the tissues making up these second-season sections. The growth rates of POJ 2878 during the formation of these sections were low and the tissues had high nodal percentages, with accompanying higher fiber content of dry matter. H 109 during the same period shows the highest sucrose percentage on a dry-weight basis, due to just the opposite set of conditions holding. It was forming cane at a good rate, proportions of node to internode were lower than 31–1389 or POJ 2878, relative moisture content was higher, and when the interactions of all these factors are considered, the juice analyses results are about what one should expect.

In all varieties there is evidence of the accumulation of sucrose with age in all parts of the plant, a condition which we have experienced in every experiment which we have carried out thus far. We have ascribed this behavior to several conditions which are induced in the cell by age: (*a*) A loss of nitrogenous colloids from the interior of the cell, as indicated by reduced total nitrogen content; (*b*) a reduction in total water-holding capacity of the cell colloids through their partial removal, as indicated by moisture data; and (*c*) a general though small increase in vacuolar volume allowing increased storage space in a given sized cell. We feel certain that we have observed this latter condition microscopically, but we admit the latter condition is largely presumptive since water content will affect colloidal volumes to a tremendous extent—so much so that simple visual observation is of little or no value in judging colloid content or properties.

Another condition, theoretically possible, is that with the reduction of nitrogen and the accompanying gradual reduction in content of reducing sugars (to a basal

FIG.24

Percentage Reducing Sugars D.M.

4 Months Section

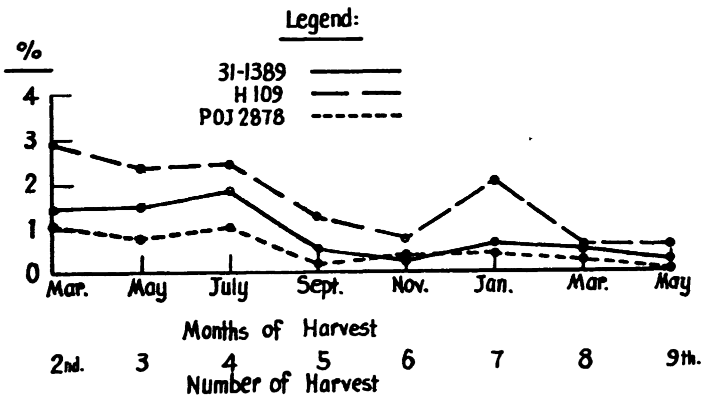
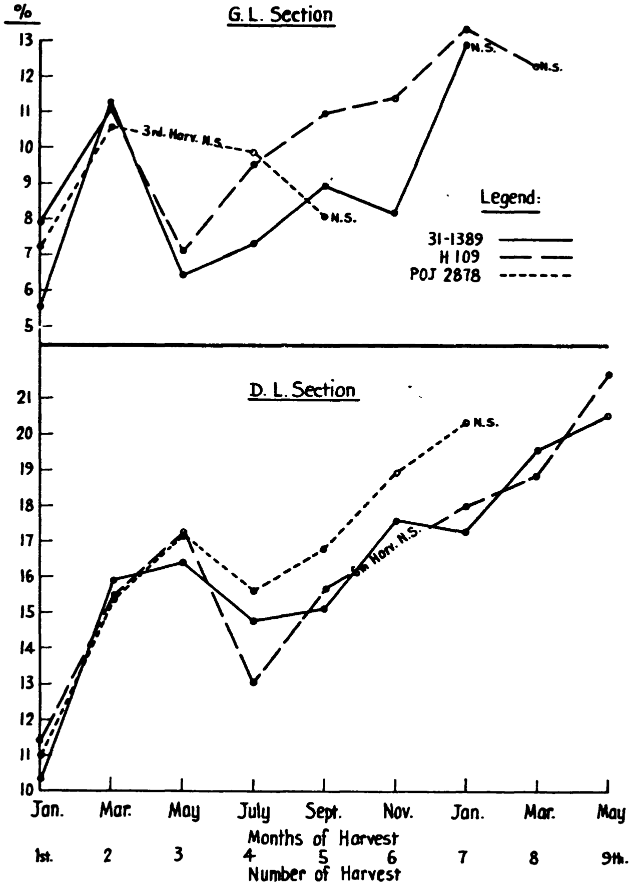


FIG. 25

Percentage Sucrose In Juice



metabolic level of .6 to 1.0 per cent on the dry-weight basis), the osmotic pressure in the cell, partially maintained by the presence of these simple sugars, is reduced and the relative percentages of sucrose can increase. From the theoretical point of view, and from measurements of osmotic pressure on sucrose and glucose solutions (6, 7), the removal of 180 units by weight of glucose from a cell would allow its replacement by 342 units by weight of sucrose without disturbing the osmotic pressure in a cell.

In this test, as in our prior work, we ran depression of the freezing point on Cuba mill juices to determine osmotic pressures of each age classification of cane. Unfortunately this method does not yield results that are identical to the osmotic pressure in the vacuole of an undisturbed, active, living cell and added errors are encountered in that the sap extraction is not 100 per cent in the Cuba mill, vascular water is mixed with the expressed cell saps and the osmotic pressures tend to be probably too low and, possibly, not even comparable between varieties—due to different varietal water content of tissues.

In our other experiments, as well as this one, it was found that when sucrose variations occurred, the contemporary opposite increases or decreases in reducing sugars, expressed either as percentage or absolute amounts, never balanced the sucrose variations. A relatively stable osmotic pressure balance in the cell maintained by variable, interacting, molar concentrations of monosaccharides and disaccharides could readily explain a considerable part of the weight and percentage variations we have encountered. This statement should not be taken to mean, however, that catabolic losses are not the important factors for the unbalance, it merely points to a possible physical mechanism of sucrose increase or decrease in the plant which will not allow direct correlation of percentage figures for sucrose and the reducing sugars in a cell of fixed volume. For direct correlation, molar concentrations of all the solutes would have to be used.

Inspection of sucrose on the dry-weight basis curves for the non-millable top and green-leaf sections shows that physiologically these two sections differ only in degree at any harvest. The varying sugar concentrations noted in these two sections at each harvest were determined on new, fresh-formed material at each harvest and thus represent the resultant of the two forces affecting sucrose supply, photosynthesis and growth at the time of harvest.

In the dry-leaf section the data represent, for the first and second harvests, increments of cane material which later makes up the four-month section. In the third and fourth harvests, the data show the conditions present in cane material which later goes to make up the eight-month section. After the fourth harvest, the data for dry-leaf sections represent the mean figures for a section of cane stalk to which has been added new material at each harvest made up of fractions coming into the more mature category during the previous two-month period. It might be almost regarded as a sliding average.

As has been described before, the four- and eight-month sections were fixed sections of stalk which one could study as units physically invariable (other than for biological sample variation) except from the internal physiological changes (which we were attempting to measure). To trace the behavior of sucrose in the juice of a section of stalk from the green-leaf stage to maturity, attention is called to Figs.

FIG. 26

Percentage Sucrose In Juice

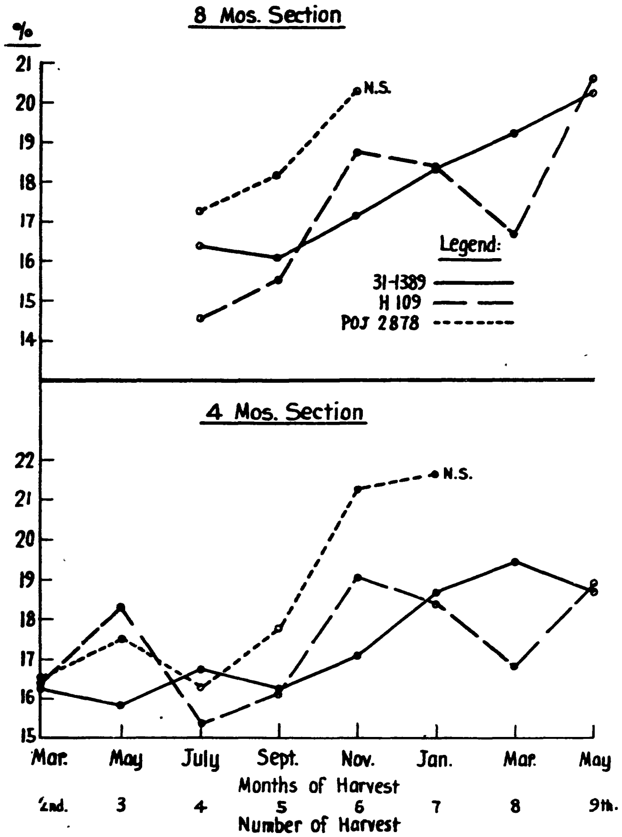
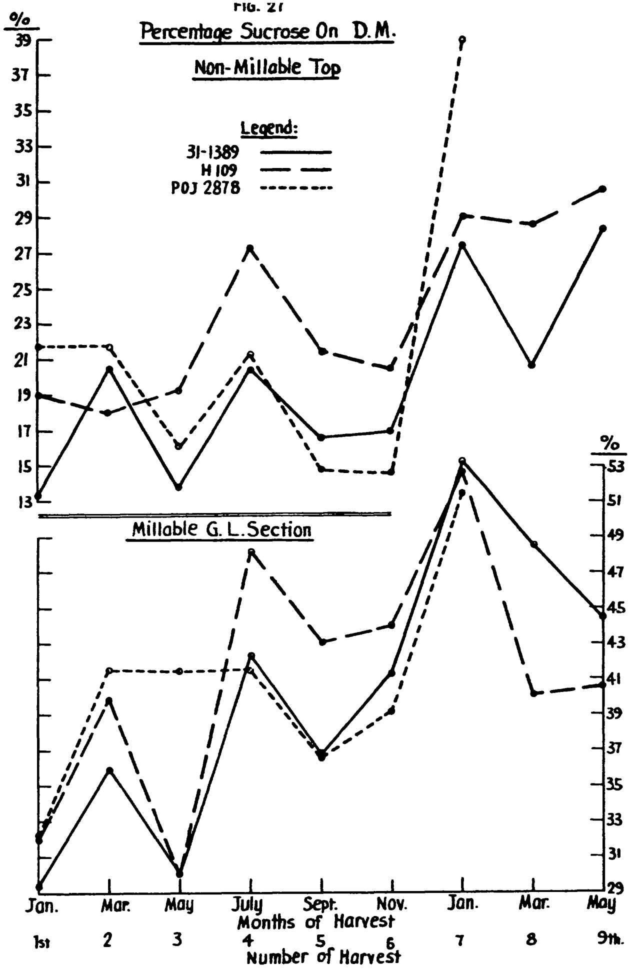


FIG. 27

Percentage Sucrose On D.M.



25 and 27, harvest Nos. 1 and 2 in the green-leaf section, and harvest Nos. 2 and 3 in the dry-leaf section; then to Figs. 26 and 28, for the eight-month section from harvest Nos. 4 to 9. The cane in the green-leaf stage at the first harvest is found two months later at harvest No. 2 in the dry-leaf stage. Two more months of fresh growth is shown in harvest No. 2, green-leaf stage, and this is found at the third harvest in the dry-leaf stage. Again the cane at the third harvest in the green-leaf stage is found in the dry-leaf stage at the fourth harvest, and so forth.

Thus for the cane making up the fixed eight-month section covering a period of initiation and of growth from November to March in the top and green-leaf stages, and from March until the end of June in the dry-leaf stage, and from then on to 24 months in the eight-month group, the sucrose percentage in juice increased roughly from five to eleven per cent in the green-leaf group, from about eleven to fifteen per cent in the dry-leaf stage, and from fifteen to nineteen per cent in the eight-month classification.

Turning to the four-month section, while it was in the dry-leaf stage of development, the sucrose in juice increased some five per cent. When this cane became a fixed section at the second harvest, little or no changes occurred in the sucrose in juice for some six months or until the fifth harvest, when an increase of some three per cent occurred in all varieties.

There is apparently no conclusion possible other than that increases occur very definitely in sucrose concentrations in juices even after the cane has reached the dry-leaf stage of maturity. It must be remembered that the juices analyzed were derived from all the cane in a 20-foot line after eight stalks were selected for analysis on a dry-weight basis and, for this reason, give fairly smooth accurate curves.

When we turn to the curves for sucrose on dry matter in eight selected first-order stalks, we find the same long-time trends apparent but they are subject to large harvest-by-harvest variations. These variations show up in the percentage of dry matter in green matter, and in the moisture curves. They indicate that the variation in sugars-to-dry-matter ratios, encountered in the same age, first-order stalks where small samples are used, may be subject to error. Properly replicated plot tests are naturally the solution to such variations. However, it was impossible for us to do the work entailed in making the large number of determinations of various kinds on more than one set of plots. As many of these determinations in this experiment had never been run before on sugar cane, we chose to run them on one-plot samples rather than have less information of a more statistically accurate nature, especially since this was a preliminary study.

### *Nitrogen Content of the Cane (Figs. 30 to 35):*

Determinations of total nitrogen were run on all age sections of primary stalks and $\alpha$-amino nitrogen determinations were run on Cuba mill expressed juices from the same age sections by Van Slyke's method.

All varieties exhibited quite similar seasonal variations in total nitrogen content, although there seemed to be an influence from varietal characteristics also. A study of the curves for the first and second harvests points to the fact that prior to our first harvest in the first-season-formed cane material, POJ 2878 had a higher nitrogen content than either of its competitors, a condition which was reversed in the material formed in the second season. A reduction in the nitrogen percentage in the first-

FIG. 28

Percentage Sucrose On D.M.

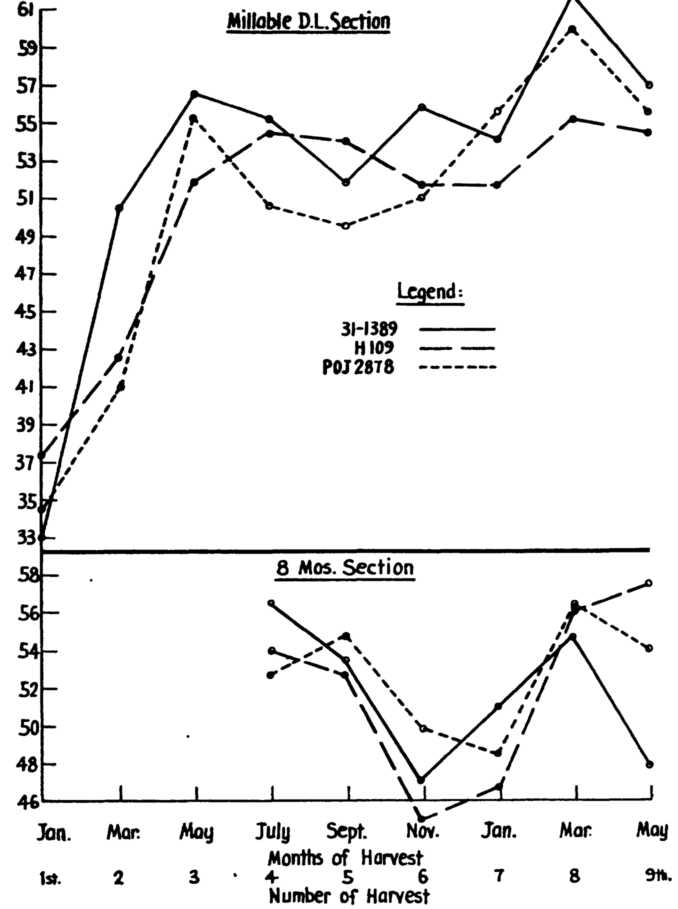
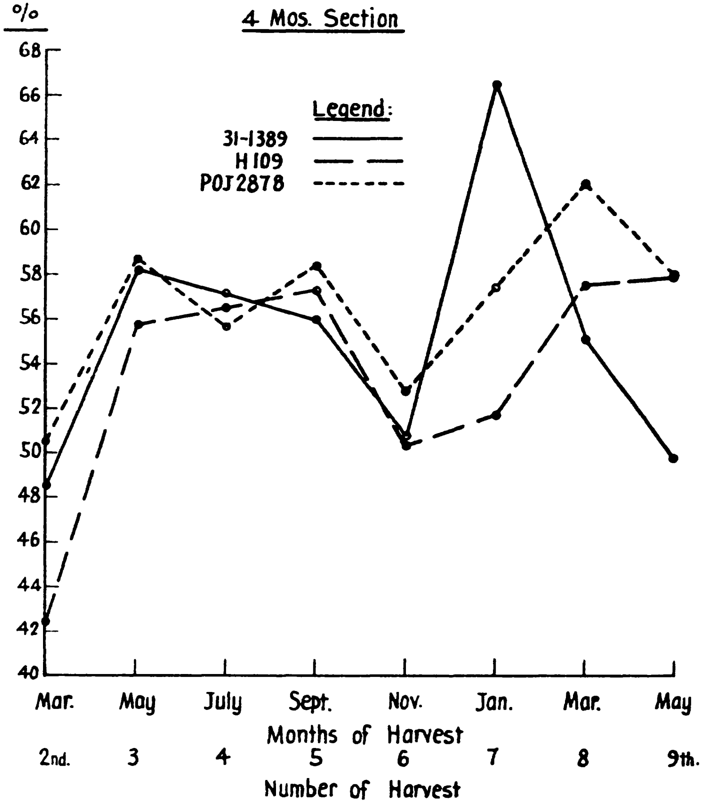


FIG. 29

Percentage Sucrose On D. M.



season-formed material appears in the second year, in fact, to a level below that in comparable stalks of H 109 and 31–1389. This reduction in the second season may have been caused by translocation to secondary stalks, which were then just in the boom stage of growth, or by nitrogen elimination through catabolism or through leaf abscission from the primary stalks, conditions which are controlled by physiological age of the variety. A comparison of the curves for total nitrogen and α-amino nitrogen in the four-month section at the fourth harvest shows that while total nitrogen in POJ 2878 is relatively low, the amino acids in the juice are high. This high percentage in the lower stalk is not followed by a rise in either the top or green-leaf sections in either total nitrogen or α-amino acids. H 109 in the same period does not show any changes in level in either total or α-amino acids. When we remember the relatively low tillering of secondaries in H 109 as compared with POJ 2878, the indications are that we have fair evidence of translocation of α-amino acid forms from the lower parts of the POJ 2878 primary stalks to the secondary stalks.

It is interesting to note the lack of parallelism of curves for all varieties in the green-leaf section when total and α-amino nitrogen are compared. A comparison of total nitrogen curves in this experiment and in our formerly reported nitrogen experiments shows that the total nitrogen figures in this experiment are of the same magnitude and trend. However, the amino nitrogen curves for the two experiments bear no resemblance to each other in the behavior of the top and green-leaf sections in the two tests. A point worth studying is the in general lower total nitrogen percentage of POJ 2878 for all sections in the second year, whereas this cane had by far the highest concentration of free α-amino acids at this period. We feel this a reflection of the physiological age of the primary stalks. Not only was there less nitrogen in all forms in POJ 2878 but there appeared to be less of that actually present, involved in cell metabolism in protein or protoplasmic form (in the second season). We feel this condition was probably reversed in the first season when this cane was making rapid growth. Both H 109 and 31–1389 were vegetatively active in the second season in the primary stalks and carried higher total nitrogen and less free amino acids than POJ 2878.

Nitrogen studies of plants are today in a highly confused state, largely due to lack of methods for either physical or chemical separation of the nitrogen fractions found in the plant into physiological-activity classifications.

From work reported previously (3, p. 173), it appears that there is considerable ammoniacal nitrogen absorbed/adsorbed on or in cell colloids. No nitrate or nitrite nitrogen forms have been found either by microchemical or analytical work in normal field-grown canes in Hawaii. As a matter of fact, chemically speaking, we would be surprised if they did occur in the presence of such large concentrations of reducing carbohydrates as cane normally carries.

As the situation is today, total nitrogen content of tissue is readily determined but of what types of nitrogen compounds that total is made up, little is known. We perforce must attempt to correlate total nitrogen with the various vegetative responses found with results which are not too pleasing in many cases.

Could we but integrate nitrogen into functional fractions in the plant, we would be much closer to a solution of our problems. Quantitive studies of protein (or protoplasmic material), of polypeptide and amino acid translocation forms, and of am-

FIG 30

Milligrams Amino Nitrogen In 100 cc. Of Juice

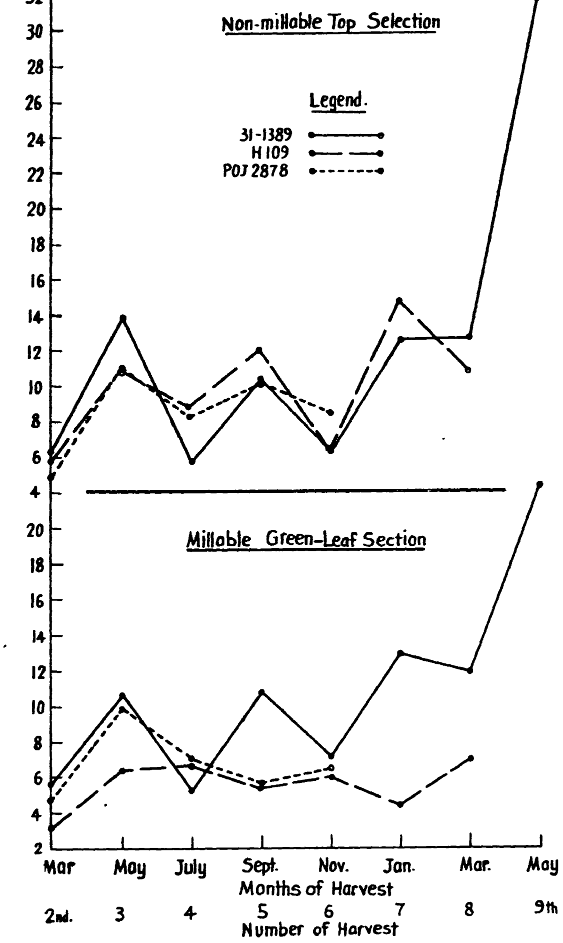
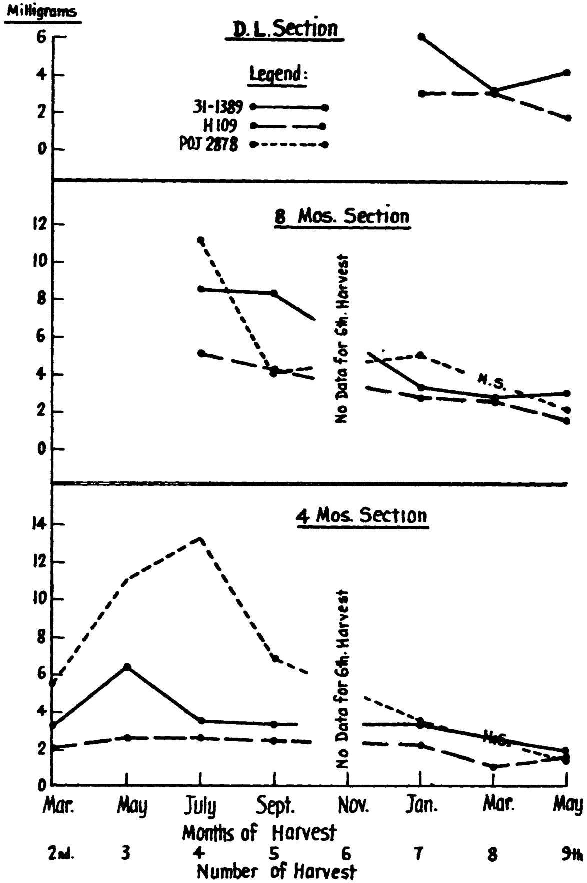


FIG. 31

Milligrams Of Amino Nitrogen In 100 cc. Of Juice



moniacal and inorganic forms adsorbed on cell colloids, would be of untold value when correlated with field data on growth rates, weights, and other determinations.

Under the heading of character and rate of elongation, mention was made of the fact that elongation rates were greatest in May even though peak temperatures and longest hours of daylight were experienced some months later. The highest mean temperatures occur at Makiki in late August and September and the longest daylight hours fall in July, so that the peak rate of growth experienced, with gradual subsidence during the summer months thereafter, is not a reflection of shortage of solar energy, but is interpreted as the effect of a nitrogen application in the preceding March followed by a gradually increasing shortage of this plant nutrient in later summer. There is a report by Dr. U. K. Das and the writer (5, p. 37) on an experiment in which fertilization was carried out at regular two-month intervals, during the first winter and the second summer of a plant H 109 crop. The graphs shown therein indicate the onset of rapid elongation in May as in this test. However, in the test referred to, there was no shortage of nitrogen imposed as a limiting factor and the growth proceeded at roughly constant rates from the latter part of May to the latter part of September. In this present variety experiment where rates were not constant, although temperatures and daylight hours were relatively similar to those of the former test, we feel safe in interpreting the results as the effects of a mild nitrogen deficiency. This nitrogen shortage is indicated in the downward trend of the total nitrogen of the top and green-leaf sections up to the November (sixth) harvest for all varieties. In the four-month, eight-month, and dry-leaf sections, there is also a strong downward trend in total nitrogen which persists through to the end of the crop, thus these sections differ from the upper stalk portions which, after November, show a gain in total and $\alpha$-amino nitrogen, a condition which we interpret as a seasonal or weather-induced accumulation of relatively inactive physiological nitrogen fractions.

While growth rates (either by weight or elongation) show H 109 to be in the lead in the second summer, studies of total nitrogen percentages for the various age sections of the three varieties show no parallel wide differences in corresponding nitrogen contents except possibly in POJ 2878. The lack of real difference between H 109 and 31–1389 nitrogen percentages in first-order stalks arose from the fact that H 109 was forming larger volumes of primary stalk material, and any additional nitrogen taken up was perforce dispersed therein. On the other hand 31–1389 was also making secondary stalk growth and part of the nitrogen taken up was being diverted thereto away from primary-order stalks and, therefore, probably would not show any differences in the primary stalk analyses results.

Our interpretation of the inference in the above set of conditions is that sugar and nitrogen percentage indices *in primary stalks alone cannot be used to predict fertilizer requirements for a crop,* since it takes into account neither population per acre (or per foot of line), varietal population distribution in the stalk-age groups, nor the effect of the timing of fertilization itself on the latter, which we have shown to be quite important (3).

The use of an index drawn from a heterogeneous sample, of all ages of stalks which have millable cane, is also untrustworthy, as we have pointed out (2, p. 282), since it may indicate depletion of the nitrogen supply too late to avoid loss of growing time.

FIG. 33

Percentage Total Nitrogen On D.M.

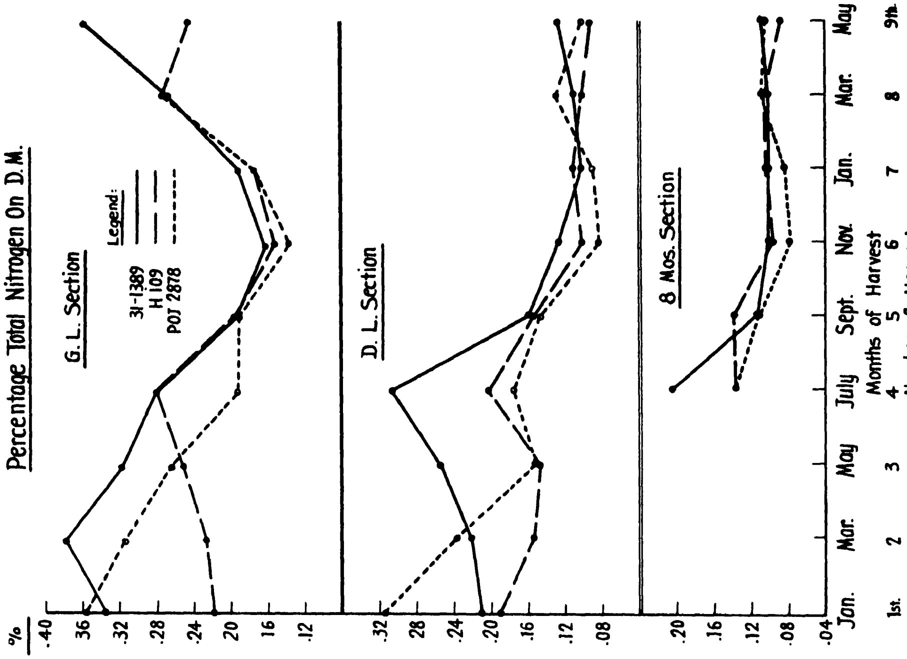
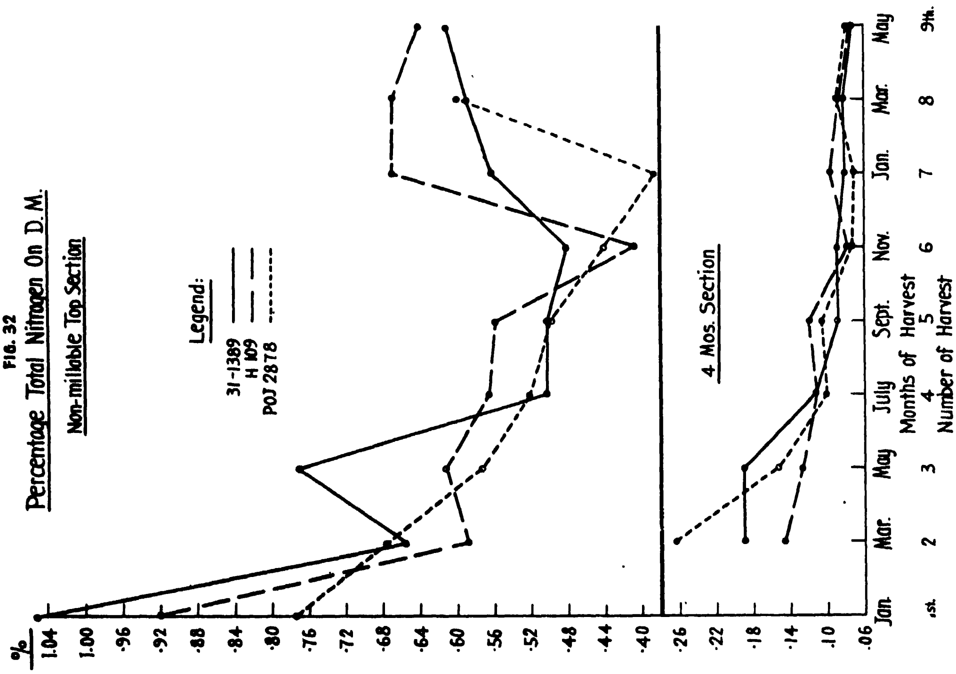


FIG. 32

Percentage Total Nitrogen On D.M.

Non-millable Top Section



The big problem to overcome in the control of nitrogen fertilization by means of sugar indices and nitrogen indices falls not so much in finding accurate index parts of the plant for use but in the interpretation and the application of these data to the crop. No index control system has been proposed which satisfactorily takes into consideration the following variables which affect our sample methods and the use of the data collected:

1. Population of stalks, and their relative age distribution in the field.
2. The soil nitrogen conditions, as they will be affected by season, location, prior treatment and weather (available and total N).
3. The prediction of weather, and the spectral type and amount of solar energy which will control plant activity during the remainder of the crop life after fertilization.
4. Varietal or genetic behavior, as correlated with the three foregoing variables.
5. How to correlate plant percentage data or absolute weight figures into the absolute pounds per acre figures necessary to apply fertilizer to the field. (This is a large problem in itself.) For an example of variable No. 1, in Figs. 3 to 7 is shown how widely the population-age of stalks may vary within three varieties. It is readily seen that data from first-order stalks of H 109 represent 65 per cent of the millable cane, but similar data from POJ 2878 are representative of less than half of the crop.

The influence of variable No. 2 has been found in a skirmish test, and data in the files at the Experiment Station indicate that there is a seasonal nitrogen cycle and a location effect influenced by light and moisture, as well as prior treatment, especially where carbohydrate material has been incorporated into the soil. Carbohydrates effect the fixation or loss of nitrogen through incorporation in soil microflora and microfauna activities.

As for Variable No. 3, prediction of solar energy, considerable work has been done on the effect of solar cycles in Canada and the United States and use is being made in Canada and Australia of sunspot data in the wheat-raising industry. However, no good correlations of spectral distribution and cane growth or sugar formation have been made, although there are air temperature and elongation correlations of value available. To date, no predictions for short-period weather, as influenced by solar cycles, are available. The entire fertilization program hinges on the solar energy (and local weather accompanying it) available for the crop period. The yearly ebb and flow of juice quality and cane tonnage of our crops under identical fertilization treatments should point to the validity of this statement.

Under the subject of varietal or genetic influences, Variable No. 4, falls not only tillering and tasseling influences but physiological behavior such as splitting, lalaing and, most important of all, the variable growth rates as influenced by chronological and physiological age. Illustration of these factors is evident in this experiment when we compare POJ 2878 and H 109 curves for the above mentioned characteristics.

The most complicated problem, Variable No. 5, involves the use of the data collected from the field sample. This brings up directly the problem of sampling or what may be taken as a criterion of the crop.

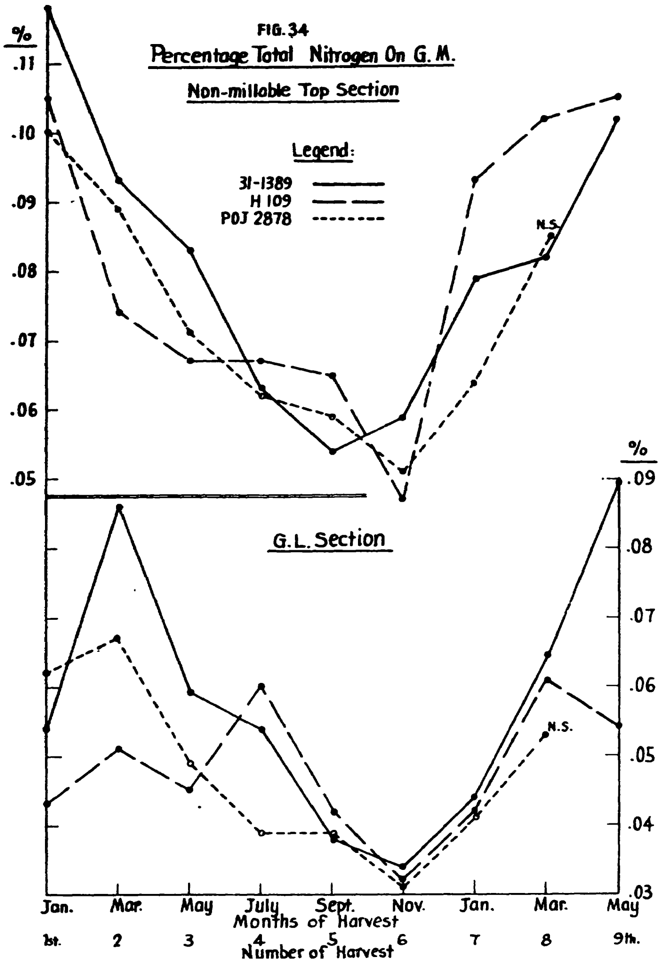


FIG. 34

Percentage Total Nitrogen On G. M.

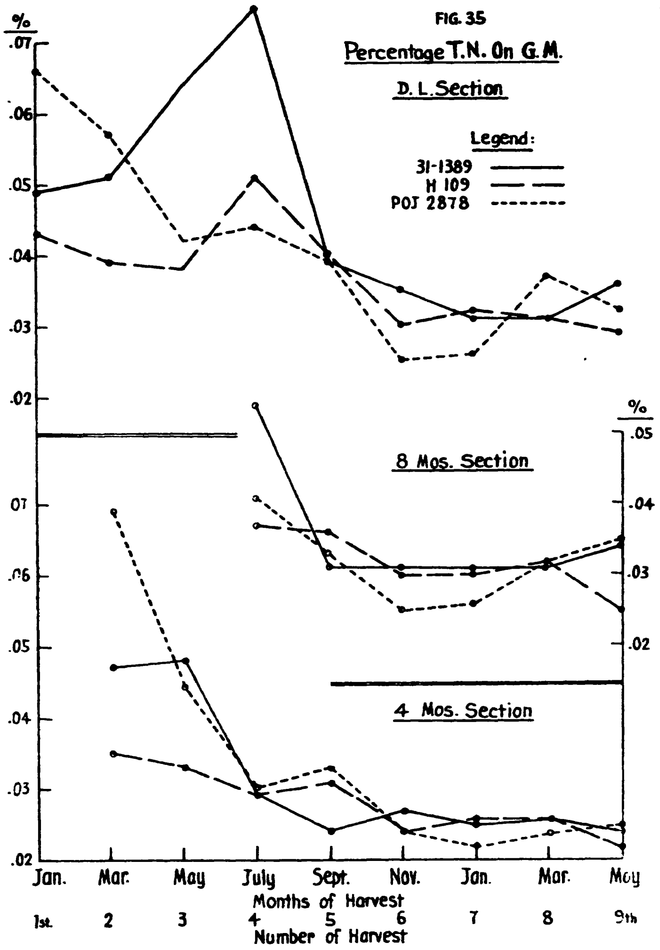


FIG. 35

Percentage T.N. On G.M.

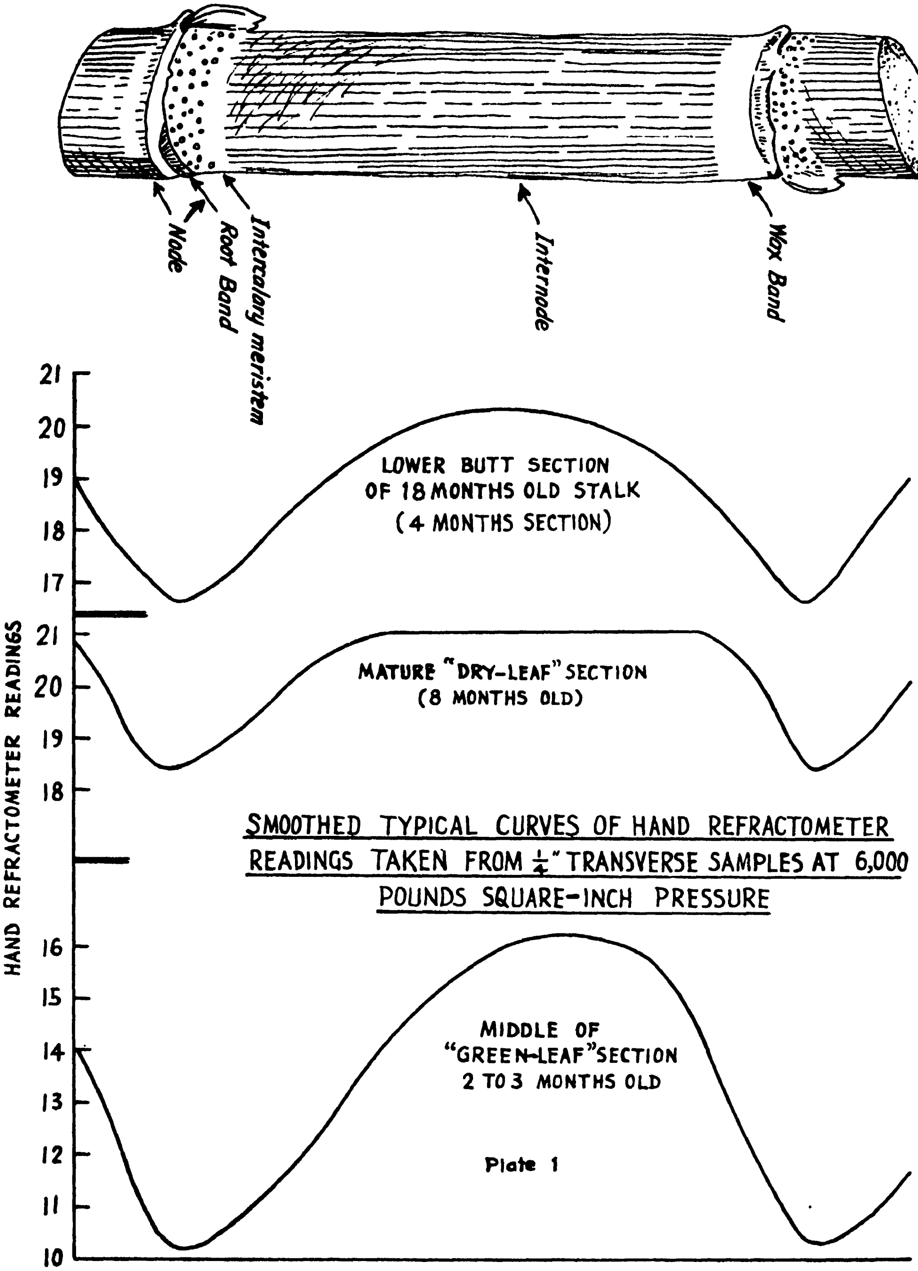
It is self-evident from the data in this paper that the selection of first-order or those stalks which carry large amounts of millable cane in the first year and which may be expected to live to harvest time, may well cause the non-inclusion of a considerable fraction of the crop made up of stalks (depending on variety and time of application of fertilizer) which will enter the millable stand in the summer of the second season. These secondary canes will be immature, poor in sucrose, high in water and salts, and will depress juice quality heavily if the field harvest is not delayed sufficiently for them to mature.

If this final maturity for secondaries is reached, mortality of primaries will be experienced in varying degrees, all controlled by the varietal responses to growing conditions. The confusing factor in taking any representative sample for index work is that after long years of cane growing and controlled experimentation, we have found that fertilization must normally be completed by the time the crop is chronologically about 12 months old and the secondaries to be found within this time, in our standard varieties, are not past the "sucker" stage of growth; thus perforce, any so-called comprehensive sample taken within the first 12-month period cannot possibly represent the final stand since it will volumetrically be influenced excessively by primary stalk conditions at sampling time.

Additionally, even though we were able to establish a satisfactory sampling procedure, our data would be expressed either in pounds (absolute) or percentage of the crop stand. To translate this percentage (or absolute pounds) of nitrogen in the plant into terms of pounds of nitrogen to apply to the soil involves as much empirical guess work as the whole fertilization program would entail, and would necessitate a long series of experiments on each soil type to determine its fixation, nitrogen loss, and rate of plant absorption, etc. To point out what happens to various amounts of nitrogen applied to a soil, attention is called to a paper by Dr. Das and the writer (5, p. 51, Fig. 2), and by Dr. Das (4). In the test referred to, we used three treatments: 133 pounds N/ac, 266 pounds N/ac, and 645 pounds N/ac applied in seven equal doses, the last dose going on by the fourteenth month. Nitrogen content of root tissue was not included in the calculations, yet in the low-nitrogen plot at eight months, we recovered 60 per cent more nitrogen than we had applied, while in the high-nitrogen treatment, we were never able to recover from the total aerial portions of plant material, 50 per cent of the amount applied. On the basis of pounds of nitrogen per acre recovered, the plots ranked in the order of amounts of nitrogen supplied, but by no means were the differences in nitrogen uptake proportional to the differences in the amounts applied. In other words, the efficiency of plant uptake (in pounds or percentage) bears little or no accurate relation to total pounds applied. In a previous article (3, p. 176) we discussed the uptake of nitrogen by the cane plant and pointed to the fact that the volume and age of plant material in the field controls largely the absolute amounts of nitrogen which will be recovered in the plant at any time.

In recent years there has been a tendency in the attempt to "streamline" crop control, to regard all variables, except the one studied or the one we are interested in, as being constants and, consequently, to either disregard them or touch on them only lightly in the reports.

We are not proposing a "defeatist" attitude toward the streamline idea in this discussion; we are merely trying to keep our feet on the ground, and to point out



SMOOTHED TYPICAL CURVES OF HAND REFRACTOMETER READINGS TAKEN FROM 1/4" TRANSVERSE SAMPLES AT 6,000 POUNDS SQUARE-INCH PRESSURE

Plate 1

that we are still a long, long way from sufficient knowledge of fundamental sugar cane growth factors to apply an effective streamline control to even our well-known varieties, let alone to the new varieties constantly entering the picture. The results of this test, we feel, present arguments for this point which are worth considering.

*Discussion:*

The results of this test are not to be construed as showing more than varietal trends and to point out differences in behavior for which to watch in later tests of a more comprehensive nature.

As can be readily seen, the largest differences between the three varieties are in the timing and type of vegetative responses each exhibits with chronologic age. This in turn, influences cane yields, sugar yields, and the adaptability of a variety to our agriculture.

The vegetative responses referred to include all types of physiological differences which in many cases do not show as individual factors in graphs of final results. Some of these we did not measure due to lack of time; on others we gathered limited information through observation at various harvest periods. Such variables as length of internode, size of leaf, diameter of stick, size of non-millable top and leaf crown, mortality of small secondaries, and hardness of rind, all fall in this category. Without such observations many of the results graphed in this test would have been considered unexplainable and highly erratic.

The behavior of the percentage of sugars on dry matter, the percentage of dry matter in green matter, and percentage of sucrose in juice figures is a case in point. They looked impossible, but observation had told us that there were varying degrees of percentage of nodal material in the three varieties. To see what part this might have played in the data, we "quick froze" a full-grown stalk and sectioned it transversely in ¼-inch sections. These we subjected to 6,000 pounds per square-inch pressure and took hand refractometer readings on the expressed juice. The resulting curves were plotted full scale for the 22-foot length of stalk (in files of Project D-1, Experiment Station, H.S.P.A. Library).

We have pointed out before that a cane stalk is a clone or made up of a community of individual plants and we have made the point that the composition of each joint or section of cane is influenced by growth conditions at the time of its formation, but we had little idea that each joint within itself would show such variability in positional concentration of solutes or that two internodes would give such unlike curves. At once, the question was opened as to corresponding fiber or dry-matter figures for the nodal portions as against the internode, and as to the relative percentage distribution of sucrose and reducing sugars in the two sets of tissues. It was decided to follow this lead in a succeeding test to be reported later.

It became evident at once that a large increase in the ratio of nodal to internodal tissue, due to slowing down of growth, would have considerable effect on sugar percentages on both the juice and dry-matter bases of calculation. This was immediately applicable in explaining the behavior of POJ 2878 in Figs. 20 to 24.

Although we ran only three stalks segmentally, it was evident that age tended to smooth out part of the node-to-internode differences by a build up of sugar content adjacent to the nodes, as well as in them.

The anatomical structure of a node and related internode also influences the sugar concentrations, at least until the internode has stopped its elongation, and has practically ceased the translocation of most of its nitrogen from the node and adjacent tissue.

In Plate 1 it will be noted that nodal green-leaf material is some six degrees lower in refractometer reading than its adjacent internodes. There is a pronounced slope toward highest sugar concentration at a point somewhat above the center of the internode, which is to be expected due to the activity of the lower intercalary meristem area, and to the fact that the internode is "pushed up" from this intercalary meristem, and that the higher cells of the internode are thus older and more mature. The downward trend at the wax band is probably attributable to activity in the area just above it in the next node and to an apparent slight increase in fiber therein due to the initiation of branching (or anastomosus) of the vascular bundles in the top part of the wax band area.

When we pass to the dry-leaf section, the sugar concentration is more uniformly spread throughout the internode; and node-to-internode differences are much less. It will be noted that the slopes of higher sugar concentration have changed and spread downward toward the meristematic area. This is probably a reflection of the cessation of elongation activity at the meristem with its accompanying utilization of potentially storable sugars.

The top curve of Plate 1 is from stalk material at the butt of a mature stalk 18 months old. Here again there is an increased difference between node and internode sugar levels. The peak internode concentrations do not seem to have been disturbed in and about the center but there do seem to be decreases at the nodes. In this area, root primordia had developed to small aerial or adventitious roots in some cases, and may account for some of the loss although not by any means all, as the condition was present in sticks not so affected. We attribute the shape of the curve in this section to either catabolic or translocation losses, the movement being probably to the root system or to new shoots.

A question interposes itself, "To what node does which internode belong?" if such a division exists. In general the evidence would point to the node below as the one which most influenced the internode above in its development since the vascular system from the leaf attached to this node could feed the intercalary meristem tissues adjacent most easily. However, in actual practice, this does not hold for we stripped two adjacent leaves from such nodes early in life and found that we had not influenced the size of the internodes or the sugar contents in the least, so far as we could determine.

The sugar readings were taken when the cane was in the dry-leaf stage and the season of observation was the early fall of the second year. The stripping off of five leaves, however, did have a detrimental effect on both sugar concentration and growth of the stalk. From these short studies it would appear that a section of stalk is influenced by the conditions in the entire top rather than each leaf having its own integral special stalk volume to care for. In our case, the removal of two leaves did not seriously discommode the plant at its specific age and photosynthetic activity level: however, we are all familiar with the incidence of leaf diseases and their effects as illustrated in the general reduction in length, diameter, and sugar concentrations in stalk material which was in the growing stage when the diseases were effective. Quite definitely in these cases, the entire growing section is involved rather than a single internode. Seasonal shortening of internodes is also sectional in effect.

A point of interest to note is that high on the stalk in the non-millable top portion the hand refractometer readings are highest for node tissue—just the contrary of conditions found eight or ten nodes below in the green-leaf portion and on down the stalk. The most readily accepted explanation is that actively operating leaves are attached at these nodes—feeding sugars through them at this stage to the rapidly elongating internodes which are consuming most of the sugars available for cell development. The nodal tissue, while immature, still is relatively more thoroughly developed or mature at this stage than the internode and has either a less, or slower, demand for sugar, or has more available than can be consumed immediately.

A few determinations were made for reducing sugar percentages, and also sucrose percentages, in the nodal and internodal tissues of the mature dry-leaf section on the dry-weight basis. While no statistical population was run, the evidence obtained seemed to point to higher percentages of reducing sugars in the internode, as well as higher sucrose content.

In the sucrose determinations, internode percentages to node percentages were as five to four, whereas in reducing sugars the ratios were two to one or three to one, indicating differences in rates of, or the types of, physiological function of reducing sugars in the two parts. The presence of apparently less reducing sugars in nodal tissue was frankly a surprise as microchemical studies had pointed to a considerably higher general nitrogen content of this tissue than in the internode proper. This nodal nitrogen was found most concentrated in the tissues of root primordia and under the lateral eyes. It was organic in composition, although whether of amino acid or protein forms, we cannot say. Based on our former findings that reducing sugars are present largely where nitrogen or protoplasmic activity is operative, we were led to the rough conclusion that the nitrogen present in the nodal tissues referred to above might be classed as "storage" forms (either to be used for eye and root growth or for translocation to more active centers) since it was not accompanied by excessive reducing sugar concentrations, i.e., $\alpha$-amino acid forms.

Comparison of older with younger stalk material showed a definite reduction in nitrogen in the node with age, providing the apex bud was still alive and reasonably active. Translocation appeared to be indicated, but nitrogen catabolism in place could have achieved the same result and should not be disregarded. It was these anatomical observations that decided us to make a study, in the subsequent tests, of the sugars in the two classes of tissues.

*Summary:*

The data from this experiment indicate that there are small differences between varieties in concentrations of sugars, moisture and other plant constituents but that the largest differences between the varieties fall in the category of vegetative type and time responses.

Large differences in rates of growth, age-types of cane in the field, longevity of stalks, number of stalks, flowering habits and variable responses to weather are indicated. The vegetative differences influence the time of appearance and magnitude of the variations in concentration of the plant constituents at any time.

The wide variations experienced under identical conditions of growth indicate that each variety must be studied for optimum fertilization, irrigation (and other treatments), and optimum harvest periods.

Special attention is called to the fact that the period of physiological maturity, rather than chronological age, will determine crop behavior in different varieties and is of utmost importance in determining the adaptability of a variety to the Hawaiian climate and cropping systems. The data point to the fact that varieties having short physiological life cycles and thereby poor "carry-over" qualities cannot be adapted to our harvesting schedules.

## LITERATURE CITED

(1) Conant, J. B., 1939. The chemistry of organic compounds. Macmillan, New York.

(2) Cornelison, A. H., and Cooper, H. F., 1940. Further studies in nitrogen nutrition-amounts-of-nitrogen test. The Hawaiian Planters' Record, 44: 273–308.

(3) ——————, and ——————, 1941. Further studies in nitrogen nutrition-time-of-application-of-nitrogen test. The Hawaiian Planters' Record, 45: 155–178.

(4) Das, U. K., 1936. Nitrogen nutrition of sugar cane. Plant Physiology, 11: 251–317.

(5) ——————, and Cornelison, A. H., 1936. The effect of nitrogen on cane yield and juice quality. The Hawaiian Planters' Record, 40: 35–56.

(6) Findlay, Alexander, 1913. Monographs on inorganic and physical chemistry. Osmotic pressure. Longmans, Green and Co., New York. (Review in Journ. Amer. Chem. Soc., 35: 839–841, 1913.)

(7) Frazer, J. C. W., and Myrick, R. T., 1916. The osmotic pressure of sucrose solutions at 30°. Journ. Amer. Chem. Soc., 38: 1907–1922.

# In Tribute

It is with deep regret that we record the death of Motojiro Sadaiki, who passed away on March 4, 1944. Mr. Sadaiki was born in Japan on May 15, 1865 and came to Hawaii on the *Yamashiro Maru*. He landed in Honolulu in May of 1899 and was first employed at Ewa Plantation Company where he worked from 1899 to 1902. In 1902 he moved to the island of Hawaii and entered the employ of the Honomu Sugar Company where he remained until his death. In 1921, when Forestry Unit 3 was organized and tree planting in the Hilo Reserve began on an increased scale, the Honomu Sugar Company assigned Mr. Sadaiki to the work of planting trees within, and adjacent to, the Forest Reserve area. Motojiro was not a young man (56 years old) when he first began this work of planting trees but up to the end of 1943, when he was retired and placed on a pension, he remained active, going out into the field to work each day. His wants were few and easily satisfied. His work was his greatest interest in life. He had found his niche and enjoyed giving all he had to his work. In 1940 he thought of retiring but when he learned that the local Forest Supervisor was being called to active duty with the Army, he decided to remain at work, saying that "I do not feel that I can retire at this time."

During the twenty-two years that he was engaged in tree planting he established an enviable record. With very little assistance he planted out and cared for a total of 423,478 trees. Of course not all of these trees lived, but his technique and experience were such that a large percentage did survive and grow. They grew, and grew well, and today they can be seen in the distance, swaying in the trade winds and forming a living monument to one man who spent more than a score of years performing a job for which he was well suited and enjoyed doing.

(L. W. B.)

# Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
DECEMBER 16, 1943, TO MARCH 15, 1944

| Date | Per pound | Per ton | Remarks |
|---|---|---|---|
| Dec. 16, 1943–March 15, 1944... | 3.74¢ | $74.80 | Philippines |

THE HAWAIIAN
PLANTERS' RECORD

Vol. XLVIII THIRD QUARTER 1944 No. 3

*A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.*

# Why a Diversified Crops Committee, H.S.P.A.?

By Harold L. Lyon

*The following statement was prepared during the summer of 1943 in answer to he questions: "Why did the H.S.P.A. appoint a Committee to promote the cultivation of crops other than sugar cane and pineapples on Hawaii's arable lands: what has this Committee done and what does it propose to do?"*

The first world war caught the residents of Hawaii quite unprepared to produce all of their own food: in fact, the possibility that it might become necessary for them to do so had never occurred to most of the people in these Islands; so when, early in 1917, it became suddenly apparent that this Territory might be denied a considerable part, or all, of the food which it was accustomed to receive from the outside world, a realization of the situation struck the community like a bombshell; it was evident that something drastic had to be done, and done at once, to forestall a calamity. There was no plan in existence to meet such an emergency and no government agency prepared to make a plan and put it into effect. Recognizing the critical situation and the need for prompt and decisive action, the H.S.P.A. stepped into the breach, took on the job of food production and assigned it to its Experiment Station. The Station accepted the mandate, analyzed the problem, and started operations along the lines which appeared to be most certain to lead to success. The Trustees made available to the Experiment Station ample funds to implement its food-production program and progress was rapid and results satisfactory. While many people in Hawaii were deprived of some of the foods to which they were accustomed, still no one in Hawaii suffered during the first world war for lack of good food. The extreme crisis which threatened never developed. However, had it arrived, we should have been able to feed ourselves.

The methods adopted by the Experiment Station in attacking the problem of food production are well illustrated in the Food Number of *The Hawaiian Planters' Record,* a publication of some 115 pages, issued in June 1917. The first four pages taken from a copy of that number of the *Record* are reproduced here.

*THE HAWAIIAN PLANTERS' RECORD,* Vol. 48, No. 3, 1944 (Copyrighted).

THE
HAWAIIAN
PLANTERS' RECORD

VOL. XVI JUNE, 1917 No. 6

**A monthly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association**

## Hawaii May Have to Feed Herself.

The Federal Government has asked this Territory to produce its own food supply in so far as possible and circumstances may actually compel us to live entirely on what we produce if the war continues for two years or more.

The world's surplus of foods is already exhausted and the feeding of the entire human race is now actually reduced to a hand-to-mouth proposition.

Under such circumstances we can readily see that the stream of foodstuffs coming to these Islands from the mainland may be seriously curtailed within the present year.

## We Must Not Reduce Our Sugar Crop.

As a food sugar heads the list as a producer of life-sustaining energy. A pound of sugar has more food value than a pound of flour, rice, beef or beans. Sugar is Hawaii's contribution to the world's food supply. It is just as much Hawaii's duty to produce a maximum sugar crop as it is Iowa's duty to produce a maximum output of corn and hogs.

This being the case, we must not encroach upon our sugar lands to the detriment of our sugar yields. We have got to produce our local food supply by more intensive agriculture, by the cultivation of all fallow fields and by the fullest utilization of all suitable lands which are now idle or only doing a very small fraction of their possible duty.

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## We Must Have Meat, Milk and Eggs.

Mainland hay and grain feeds are now soaring to unbelievable prices and may soon be, to us, unobtainable at any price. An impending milk shortage is already discernable and a rapid decrease in hog and poultry products may be expected.

So far as cattle and horses are concerned the feed shortage can be relieved to a large extent by using the excess of green cane tops and molasses now going to waste on the plantations. In addition to feeding the cane tops when fresh, they may be made into silage or shredded and cured into hay for use during the off season.

With the feed afforded by the present ranches and the cane tops and molasses available for stock feed on the plantations Hawaii can feed enough cattle to supply the milk and beef requirements of all the people on these Islands and eventually have beef for export.

The conversion of cane tops and molasses into milk and beef calls for no additional land and no more additional equipment or labor than would be well paid for by the values produced when feeds are at normal prices.

Hogs will eat some silage and a considerable amount of pineapple refuse, but we must grow corn, sweet potatoes, beans and peanuts to take the place of the starchy and nitrogenous grain and mill products now imported for hog feed.

Home grown corn, sweet potatoes, milo maize, sunflower seed and pigeon peas will fill the grain requirements of our poultry.

Belgian hares thrive on the green pods and leaves of the lowland koa. They are very fond of pualele and will eat honohono and many other of the common weeds. The prunings from an hibiscus hedge are a welcome addition to their diet. The feeding of Belgian hares, therefore, requires no extra agricultural effort. It is purely a matter of conservation.

## What Crops Shall We Plant?

We do not recommend the trial of new food plants at this time. We cannot afford to sacrifice a sure crop in order to try a new and uncertain one. We already know that certain things can be grown successfully on our lands and seeds and cuttings are already available for their planting. Standard and tested crops such as rice, taro, sweet potatoes, bananas, beans and peanuts should receive first attention. Corn should be grown when and where conditions suit it.

The food materials imported by these islands during 1916 represented the actual amount of additional food which we should have had to produce during that year to be self-supporting. For practical purposes these imports, listed on pages 446-449, may be taken as representing the amount by which we must increase our yearly output if we are to become self-supporting. We cannot hope to duplicate these commodities kind for kind, but we can easily reckon their food value in terms of protein, fats and carbohydrates, and then direct our energies towards producing the required amounts of these three nutrients. The tables on pages 462-465 supply the additional data necessary to make these computations.

*For Carbohydrates*: While we will probably use an increased amount of sugar, still the greater part of the carbohydrates now imported must be replaced by starchy foods such as rice, taro, corn, bananas and sweet potatoes.

When all the idle lands suitable for rice and taro are under cultivation, their output will make only a small contribution towards our total requirements. Corn does well in certain districts only and can not be recommended for general planting. While the banana supplies an excellent food, it would not, for several reasons, be selected as an emergency starch producer

The sweet potato, then, is left as our last hope and we could not ask for a brighter one. The sweet potato is a rapid growing, quick maturing crop and will yield more digestable carbohydrates per acre per year than any other food crop suited to our conditions.

We can increase our sweet potato yield a hundred fold without diminishing our sugar or pineapple crops.

*For Protein and Fat*: To produce the protein and fat now imported, which we cannot replace by an increased production of meat, milk, butter and eggs, we must grow beans and peas of various sorts. All of the well-known garden varieties of beans and peas are rich in protein and at the same time contain some fat and considerable carbohydrates. Soy beans and peanuts are especially rich in fat; the former is not a sure crop in Hawaii, however, but the latter can be relied upon to give good returns. Peanuts are easily grown and the seeds contain forty to fifty per cent of fat.

The coconut is a very important source of fat in most tropical countries and it is unfortunate that these Islands have not now a well-developed coconut industry. Coconuts should be planted now to help out in future emergencies.

*Green Vegetables*: Hawaii grows a reasonable amount of this class of produce under normal conditions and an over-production of garden truck will be the most natural result of the present grow-your-own-food agitation.

We feel that this phase of the food production campaign needs no special promotion on our part. Overproduction of perishable garden truck will result in waste of produce and discouragement of its growers.

Beans and sweet potatoes can be fed to horses, cattle and hogs in lieu of grain. They can be stored for months or shipped to distant markets.

There is no doubt but that Hawaii can feed herself If compelled to do so, beans and sweet potatoes must be her "staff of life."

# MISCELLANEOUS FOOD CROPS ON SUGAR PLANTATIONS.

By L. D. Larsen

~~The concensus of opinion among those who have studied the situation indicates that sugar is by far the most important commodity that can be raised on our plantations at the present time. In view of the national food shortage we are urged to use every effort possible for increasing or at least upholding our usual sugar production. No one suggests curtailing the sugar area to produce other food stuffs.~~

~~It is imperative, however, that other food crops be grown on a much larger scale in these Islands than has heretofore been the case, and it is evident that a large share of this increased production has to take place on the sugar plantations.~~

~~The object of this article is to point out some of the means that have been suggested or which have already been adopted in various parts of the Islands for accomplishing this end.~~

~~For the sake of brevity we shall discuss our subject under four separate headings:~~

1. ~~Waste lands,~~
2. ~~Fallow lands,~~
3. ~~Camp gardens,~~
4. ~~Interplanting with cane.~~

On pages following those reproduced were articles describing the more important food crops that could be grown successfully in Hawaii and giving pertinent information regarding their culture. One article gave the name and quantity of each and every kind of food that had been brought into the Territory during the preceding year. This enabled us to estimate the nature and amounts of additional food materials which would have to be produced locally should Hawaii be compelled to feed herself.

Farmers' Bulletin No. 142 of the U.S. Department of Agriculture (1917), entitled "Principles of Nutrition and a Nutritive Value of Food," was reprinted in full in this issue of the *Record* and enabled anyone to compute the relative values of various food materials. On the whole, this Food Number of the *Planters' Record* constituted a practical manual supplying all the data necessary for formulating and executing a program of food production for the Territory.

The fact that a realization of the necessity for a food-production program came one day in 1917 and the financing and launching of the program were virtually completed the next day is a striking example of the rapid-fire efficiency of the H.S.P.A. organization. Any situation arising that jeopardizes the economy of this Territory which can be appropriately handled by the H.S.P.A. may be considered, and its alleviation provided for, within a few hours after its recognition.

Recalling the difficulties in food production which suddenly confronted Hawaii during the first world war, the H.S.P.A. was determined that the Territory should not be caught equally unprepared should a later war involve these Islands. It was realized that should an emergency arise, say in 1940, that required these Islands to produce all of their own food, the problem would be far more difficult than was the problem in 1917 so, in 1935, the H.S.P.A. organized its Diversified Crops Committee, one of the prescribed functions of which was to draw up plans for food production to meet any emergency that might check or stop the flow of food supplies into Hawaii.

As an easy means of describing the efforts of this Committee in planning for food-crop production to meet any emergency, we reproduce a letter written to Governor Poindexter in June 1941:

June 19, 1941.

The Honorable Joseph B. Poindexter,
Governor of Hawaii,
Iolani Palace, Honolulu, Hawaii.

My dear Governor Poindexter:

In compliance with your request, I submit the following brief statement regarding what has been done and what should be done to insure an adequate food supply for Hawaii in case of an emergency.

*The Diversified Crops Committee:*

In 1935 the H.S.P.A. called together, as a Diversified Crops Committee, a group of men representing all phases of agricultural endeavor in the Territory. Ever since its inauguration, this Committee has functioned continuously and at the present time its membership is as follows:

H. P. Agee
J. H. Beaumont
F. W. Broadbent
D. L. Crawford
A. L. Dean
A. D. Ednie
Col. Casey Hayes
L. D. Larsen
H. L. Lyon
W. W. G. Moir
H. H. Warner
Neil Webster

While the primary function of the Diversified Crops Committee was to find new crops that could be grown in the Territory with profit to the growers, it has from the very first given much attention to plans for producing, locally, crops in such quantities and of such a nature as would provide the entire population with adequate subsistence in case some emergency stopped the flow into the Territory of foodstuffs from outside sources. During the past year, all the efforts of this Committee have been focussed on this one objective.

### *A Food Administration with Authority an Obvious Necessity:*

The Diversified Crops Committee has at all times held the opinion that whenever an emergency develops necessitating the local production of a large part or all of the food required to feed the people in this Territory, a Food Administration would be set up and financed by the Federal Government, and given unlimited powers to requisition land, water, labor, machinery, fuel and all seeds and cuttings of food plants.

The Diversified Crops Committee has, through long-continued efforts on the part of its members and their associates, worked up feasible plans for food and feed production in this Territory with the intention of placing these plans at the disposal of a Food Administration if, and when, such an Administration was created.

On request, the Diversified Crops Committee can supply inventories of stocks of essential foods, feeds, fuels, etc. present at the time in the Territory and can also provide an estimate of the cost of any operation which it recommends.

### *If Prepared for the Worst, Any Lesser Emergency Can Be Easily Handled:*

It is quite probable that if an emergency develops, the Territory will experience a gradual curtailment of transportation facilities but we should be prepared to meet promptly the worst possible situation. As the bulk of the Territory's population resides on the Island of Oahu, the most serious situation that can arise is the complete isolation of Oahu, not only from the mainland but from the other islands in the group as well. The Diversified Crops Committee has prepared a food production plan to meet this critical situation should it ever arise. If some agency is authorized and financed to carry out this plan to meet the worst possible situation, it will be able to cope rather easily with any situation of lesser severity which may be inflicted upon us. The Diversified Crops Committee has, therefore, drawn up a Basic Plan to meet the extreme situation; this plan being so drawn that it can be put into effect by increments, the entire plan becoming effective only when the extreme situation is about to be realized.

### *Adequate Funds Should Be Made Immediately Available:*

If the extreme situation develops—that is, complete isolation of Oahu—the conditions which make this possible will render such exposed sections of the Island as Waianae, Kahuku and Waimanalo unfit and unreliable for farming operations; therefore, plantings for the extreme emergency should be confined to the four major and centrally located plantations. The lands of these plantations are among the most highly productive in the Territory and their use for growing diversified crops will represent a heavy financial investment. The minimum area of irrigated lands required for planting under the Basic Plan is 8,700 acres. These sugar cane lands, when requisitioned, will all be carrying heavy crops of cane and it will require much energy, labor and expense to get this cane out of the ground, put the land in shape and plant other crops. Seeds and propagating material for the crops to be planted must be grown or purchased.

Seeds for some crops can be purchased from outside sources but those for others, such as pigeon pea, must be grown locally. The sweet potato should be our most extensively planted food crop as it is our most reliable, but we shall have to have much more propagating material than is now available in the Territory. Steps should be taken at once to secure appropriate land and grow thereon the propagating material of the essential crops which will be required for the initial plantings under the Basic Plan.

The planting, cultivating and harvesting of the food crops that must be grown will require special machinery not now to be found on sugar plantations or elsewhere in the Territory. The procuring of this machinery should be attended to at once as it will take time to get it here from the mainland. Following recommendations of the Diversified Crops Committee, the H.S.P.A. has already invested several thousand dollars in emergency machinery, but this will only serve to demonstrate what is needed. The H.S.P.A. has also spent many thousands of dollars on the promotion of diversified crops through field and feeding experiments carried on under the supervision of the Diversified Crops Committee.

### *We Must Grow Crops for Feed:*

In addition to growing food crops for human consumption, we must grow crops to feed beef cattle, dairy cattle, hogs and poultry, for we must have meat, milk and eggs. The by-products of the sugar and pineapple industries will be employed to advantage as feed, but these will not go very far towards fulfilling requirements. We must grow forage crops for cattle, root crops for hogs and seed crops for poultry.

### *Protein Foods and Feeds:*

A life-sustaining diet for all animals including man must provide a considerable amount of protein, that is, organic compounds containing nitrogen. Hawaii's standard crops are notoriously rich in carbohydrates but very low in protein. As a consequence, the Territory imports, under normal conditions, large amounts of foods and feeds which supply protein. To provide adequate protein for human consumption and for stock feed will be one of the most serious problems to be solved in an extreme emergency.

All plants can make protein out of carbohydrates and inorganic nitrogen, but animals do not possess this ability, so must derive all their proteins from plants. The sugar cane, pineapple and banana make protein for their own bodies, but place very little of it in the products which we recover, so, in an emergency, we must grow plants that put protein in that portion of their bodies which we, as humans, use for food. Bean plants deposit a lot of protein in their seeds and, as we can grow many varieties of beans successfully in Hawaii, they constitute one crop on which we can rely for a considerable part of our protein in an emergency.

Another crop rich in protein, the cultivation of which is being advocated by the Diversified Crops Committee, is yeast. This lowly organism can be grown easily in a weak sugar solution to which has been added ordinary fertilizer salts. It feeds on the sugar and, picking up the nitrogen and mineral elements, builds up protein, growing at a prodigious rate. The yeast organism does not construct a complicated body but merely clothes its living substance with a thin membrane. A mass of dry yeast, therefore, is largely protein. Under favorable conditions, which are easily maintained in any climate, a crop of yeast grows to maturity in less than 24 hours, so it is quite possible to harvest a crop every day in the year.

At a pilot plant in Honolulu, financed by the H.S.P.A., all the details of yeast production as a commercial crop have been worked out. The dry product is 50 per cent protein and very rich in the vitamins of the "B" complex. It is quite palatable and a number of people have, for some time, been eating it regularly to determine its value as a source of protein in the human diet. Their reactions are all very favorable. Up to the present time, most of the output of this pilot plant has been used in feeding experiments at the University with cattle, hogs and poultry. The results of these experiments clearly indicate that yeast is an excellent source of protein for these food-yielding animals. However, since this yeast has proved to be a good protein food for humans, it would be poor economy to feed it to beef cattle in an emergency, for it will be necessary to feed at least 10 pounds of yeast protein for every pound of protein recovered in beef.

Since an abundance of sugar will always be available on Oahu, the Diversified Crops Committee recommends that adequate facilities be provided so that in an emergency yeast may be produced in large quantities for food and feed. Under our conditions, the culture of yeast affords the surest and quickest method of producing the essential protein.

### *Stores and Storage Most Essential:*

It will be at least six months after operations under the Basic Plan have been started before its returns will fully meet the needs of the population, so it is essential that we have on hand supplies of food and feed to carry us through this critical period.

We have learned by experience that crops cannot be successfully grown on our lands unless they are supplied with adequate fertilizers and as all fertilizers used in Hawaii are brought in from outside sources, it is essential that an adequate supply of these materials be imported and held in reserve for use in case an emergency develops.

In order to combat the diseases and insect pests which are certain to attack the divers crops which we must grow in an emergency, we should have on hand an adequate supply of appropriate insecticides and fungicides. These materials should be brought into the Territory while transportation facilities are still available.

Most of the energy consumed in the Territory outside of sugar factories is derived from fuel oil, Diesel oil and gasoline brought from the mainland. We cannot have electric lights and electric power if the flow of these fuels from the mainland is stopped. Most of the water used for domestic purposes and irrigation on Oahu is pumped from wells with power derived from fuel oil. Deprive Oahu of fuel oil, and the water supply of Honolulu would fail completely, while most of the cane fields on the Island would have to go without water and the crops which they carry would be ruined. Deprive Oahu of Diesel oil and gasoline and it would be impossible to operate the machinery necessary to the cultivation of field crops. It is most essential, therefore, that if an extreme emergency is impending, large supplies of fuel oil, Diesel oil and gasoline be held in storage on Oahu for, if our power supply fails, we will be unable to survive long.

*Cultivation of Truck Crops in Hawaii Not Profitable Under Normal Conditions:*

The chief aim of agriculture is to capture radiant energy by means of crops which store it in products which can be utilized by man. Of all known crops, sugar cane is the most efficient producer of such products and, consequently, its cultivation adds more to our national resources in a given time than can the cultivation of any other crop. So long as normal transportation between Hawaii and the mainland can be maintained, Hawaii can contribute most to our national resources by growing sugar for shipment to the mainland, and most to our national prosperity by buying from the mainland products produced more efficiently there than they can be produced in Hawaii.

Hawaii is tropical and its fields are not suitable to the cultivation of temperate zone crops. If such crops are grown, the yields are not comparable with those obtained in temperate climes.

It should be obvious to any student making a careful examination of the situation that anyone undertaking the production of truck crops in Hawaii on a scale sufficient to satisfy the local demand for these crops is embarking on a course that will lead to financial disaster if mainland produce has continued access to our market. If Hawaii must undertake the production of food crops to tide her through a national emergency, the Federal Government should underwrite the enterprise, as it cannot survive when the emergency is passed and will be liquidated at a considerable loss to its promoters.

Yours respectfully,

(Signed) Harold L. Lyon,
Director.

After carefully considering the confusion and even panic which might possibly be induced by such a course, the Diversified Crops Committee early in 1941 instigated and promoted among the civilian population throughout the Territory a campaign of buying and storing for a possible emergency such food products as rice, flour, beans and canned goods. The people of Hawaii promptly grasped the idea and, with enthusiasm but without any hysteria, bought and stored on their own premises large amounts of food. This relieved much warehouse space which was promptly filled with new goods from the mainland. By buying and storing food materials in the early months of 1941, the people of Hawaii contributed much to the favorable food situation which has been constantly maintained in Hawaii up to the present time.

The Diversified Crops Committee carried on investigations, financed and conducted experiments in the field and, on the basis of its findings, made plans for food production to meet any emergency that might arise. There were certain very important lines of investigation which it could not undertake and, because of this, it could not obtain certain information which was most essential in rounding out its plans. The misgivings of the Committee were expressed in a letter to the Trustees which we reproduce hereunder:

August 11, 1941.

The President and Trustees of the
Hawaiian Sugar Planters' Association,
Honolulu, Hawaii.

Dear Sirs:

The Diversified Crops Committee, H.S.P.A., has directed its attention in recent months almost exclusively to the formulation of plans under which the Territory of Hawaii might produce sufficient food to sustain its population in case an emergency stops the flow of foods from the mainland.

You have been advised from time to time of the Committee's progress with these plans, which are now nearing completion. Under instructions from the Committee, its Chairman discussed the food production situation with Governor Poindexter and, at his request, prepared a statement, a copy of which is attached hereto.

At the last meeting of the Diversified Crops Committee (August 1), it was moved, seconded and voted:

> "THAT the chairman of the committee present to the Trustees the serious nature of the whole problem of production and storage as brought out in the discussion by the members present and request the instructions of the Trustees as to the future course of the committee."

If the flow of foods to Hawaii from the mainland is stopped, the flow of other materials will also be stopped. It will be absolutely essential, therefore, that we have on hand in this Territory, when transportation is halted, all the materials necessary to implement our food production plans: otherwise, our plans will be of no avail. When the crisis arrives, we should have immediately available ample planting material of the crops to be grown and the special machinery required to handle these crops. We should have in storage supplies adequate for a year or more of the fertilizers, insecticides and fungicides required in the culture of our special food crops. We should also have in storage large quantities of feeds for our dairy cattle and poultry and finally, we should have in reserve large supplies of fuel, for our food-production operations cannot be carried on, as planned, after our fuel supply is exhausted. The Diversified Crops Committee has repeatedly pointed out the absolute necessity of obtaining these essentials prior to the emergency, but no steps are being taken to provide them. Lacking these essentials, the Committee's plans cannot be executed so it will have but wasted time in making them.

The length of time that Oahu can survive a total blockade will be determined by the amount of fuel on hand to operate its essential utilities. Honolulu's water supply, electric current, gas and transportation facilities all depend upon imported fuel. The cultivation of food crops on a major scale and their distribution will consume much fuel. It should be obvious that fuel will be the very backbone of Oahu's resistance to a blockade; yet, the fuel question is receiving scant attention. The importation and storage of fuel and plans for its conservation during any emergency should be receiving the immediate attention of the very best men available for the job. The conservation of fuel will be one of the most important measures in defense and every operation proposed as an emergency measure should be carefully examined with reference to its probable fuel requirements before it is approved.

When an emergency is impending, it will be necessary to obtain and store in the Territory enough food to feed its population until locally produced foods are available in sufficient amounts. It is estimated that it will cost around 2½ million dollars to provide sufficient imported food to carry the population on Oahu through the first six months of an emergency. It will cost equally as much to finance our food production plans for Oahu and carry them through the second six months of an emergency. The question naturally arises, therefore, would it not be safer and more economical to buy and store a year's food supply rather than attempt to fully implement our food production plans. It certainly would be safer, for the cultivation of temperate-zone food crops on these tropical islands is always a hazardous undertaking, for crop failures are the rule rather than the exception. The concentrated foods required for the second six months of an emergency would hardly be more bulky for transportation than the fertilizers, insecticides, fungicides, special machinery, feeds and extra fuel which it will be necessary to import in order to execute our food-production plans. The use of imported foods would be a good way to conserve fuel.

Now, we do not wish to have you gain the impression that your Diversified Crops Committee holds that its food production plans cannot be carried through, but it does wish to let you know that the steps to implement these plans, which must be taken before transportation is curtailed, are not being taken and that when transportation is curtailed, it will be too late to take these steps. We wish to make this clear at this time so that we will not be called upon to do the impossible when an emergency arrives.

Yours very truly,

DIVERSIFIED CROPS COMMITTEE, H.S.P.A.,
By (Signed) HAROLD L. LYON, Chairman.

In November 1941, the Diversified Crops Committee transmitted to the Trustees of the H.S.P.A. detailed plans for food production throughout the Territory; plans which might be implemented to a sufficient degree to meet any food emergency that could arise, ranging from one entailing a slight decrease in imported foods up to one imposed by a total blockade, when we should have to produce enough food to supply all the needs of the Territory. These plans were made available by the H.S.P.A. to the Army and to any and all other government agencies that might wish to have them. Immediately following the attack on Pearl Harbor, martial law was imposed upon Hawaii and the United States Army immediately assumed control over Hawaii's food supply and responsibility for maintaining it.

There is a very great diversity in the kinds of foods that might be supplied to feed adequately the people in this Territory. The *most pleasant situation* prevails when everybody gets all they want of each kind of food that they are accustomed to. The *most unpleasant situation* would exist when everybody was supplied each day with a subsistence ration only, and this composed of the same commonplace ingredients day after day. Now, no one relishes the experience of living for months almost entirely on sweet potatoes and beans: yet, that is exactly what they would have to do should Hawaii be deprived of its ocean transportation facilities. Despite stupendous difficulties which it could not mention but had to overcome, Hawaii's Food Administration has, since December 7, 1941, kept the people of this Territory unbelievably close to that "most pleasant situation" outlined above. In no other locality in the United States have the inhabitants been so well supplied with the necessities and luxuries of modern life as have the civilians in Hawaii. This is the more remarkable because most of these necessities and luxuries had to be brought to the Territory on steamers crossing submarine-infested waters and during a period when rapid transportation of military personnel, equipment and supplies was most urgent. Taking everything into consideration, the people of Hawaii should have only admiration and praise for the men who have managed to keep an abundance of good food always available to the people of this Territory.

Immediately following the outbreak of war, the Food Administration in the Office of the Military Governor took over all of the functions which the Diversified Crops Committee had previously performed voluntarily. This was exactly what the Diversified Crops Committee advocated and anticipated, as expressed in our letter of June 19 to Governor Poindexter. Although relieved of the leadership and of all responsibilities in the field of food production, the Diversified Crops Committee has continued in existence, but has had no part in the execution of the emergency food-production program. Under the circumstances, the individual members of the Committee and their subordinates have made their contributions towards food production through the Food Administration rather than through the Diversified Crops Committee, H.S.P.A.

As soon as peace is reestablished throughout the world and we can again secure materials from all corners of the earth, the Diversified Crops Committee, H.S.P.A., will resume its search for new crops that can be grown in Hawaii with profit to the growers.

# Experimental Forest Planting
## Mauna Kea, Island of Hawaii

By L. W. Bryan

In 1909–1910 Forester Hosmer imported from the mainland and Australia a number of different species of conifers and hardwoods for experimental planting. The object of this experiment was "to introduce into the forest flora of the Territory of Hawaii valuable timber trees from the temperate zone with the idea of ultimately turning to economic account, through timber production, the upper slopes of the higher mountains of the Territory."* The species introduced were planted out at different elevations on the slopes of Haleakala on Maui, and Mauna Kea on Hawaii. Originally the planted areas were protected by stock-proof fences but when the writer first visited the plots on Mauna Kea in 1921, all of the fences were found to be in very poor condition, the trees were unprotected, and wild sheep had done considerable damage.

*Pinus jeffreyi* and *Pinus coulteri*, Plot No. 1, elevation 7,450 feet, Mauna Kea at Puu Laau.

On Hawaii four plots were located all on the west slope of Mauna Kea and briefly described as follows:

| | | |
|---|---|---|
| Plot No. 1—Puu Laau | elevation | 7,450 feet |
| Plot No. 2—Puu Ulaula | elevation | 9,000 feet |
| Plot No. 3 | elevation | 10,875 feet |
| Plot No. 4—Puu Kemole | elevation | 7,130 feet |

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* Kraebel, C. J., 1922. Report on experimental forest planting at high altitudes of Maui and Hawaii. The Hawaiian Forester and Agriculturist, 19: 151–158.

As Plots Nos. 3 and 4 contain comparatively few trees (Plot No. 3 only 1 and Plot No. 4 only 13), and as they have remained unprotected from damage by wild sheep, they will not be included in this summary. Fences around Plots Nos. 1 and 2 were rebuilt in 1926 and these fences have been maintained since in stock-proof condition.

Measurements were made in 1921 by Kraebel* and Bryan; in 1927 by Bryan and Lindsey; in 1933 by Bryan and Kawai; and in 1944 by Yamayoshi and Kawai. Spot measurements were made in 1921 and averages arrived at for each species. In 1927 each individual tree was carefully measured and a copper tag bearing a reference number was placed thereon. This same method was followed again in 1933 and in 1944, and an accurate record is available for each tree growing in these two plots.

The original list of trees planted by Hosmer contains the names of many species which apparently did not survive as no specimens were found alive in 1921. The original list of species tested contained the names of 49 conifers and 37 hardwoods. Failure of many of the species planted, particularly the hardwoods, can be attributed to the fact that they were planted at too high an elevation and on the dry slope of the mountain. Since then most of the same species of hardwoods have been planted at lower elevations (5000 to 6000) on the wet side of the mountain and have proved successful. Of the original hardwoods planted only one species, *Eucalyptus robusta*, has survived. Seven trees of this species are still growing in Plot No. 4 at Puu Kemole.

Species that have survived are shown in the following tabulation with average of measurements taken at the four periods mentioned.

| Species | Plot | 1921<br>Avg. ht. | 1927<br>Avg. ht. | <br>Avg. dia. | 1933<br>Avg. ht. | <br>Avg. dia. | 1944<br>Avg. ht. | <br>Avg. dia. |
|---|---|---|---|---|---|---|---|---|
| *Cedrus deodara* (69 trees) ..... | 1 | 8.0′ | 4.5′ | .4″ | 10.9′ | 1.4″ | 23.6′ | 5.2″ |
| Average increase ........... | 1 | .... | —3.5′ | ... | 6.4′ | 1.0″ | 12.7′ | 3.8″ |
| *Libocedrus decurrens* (53 trees) | 1 | 11.0′ | 11.7′ | 3.1″ | 17.4′ | 6.4″ | 26.8′ | 10.3″ |
| Average increase ........... | 1 | .... | .7′ | ... | 5.7′ | 3.3″ | 9.4′ | 3.9″ |
| *Pinus coulteri* (42 trees) ...... | 1 | 14.0′ | 17.7′ | 6.1″ | 25.1′ | 9.2″ | 35.7′ | 13.5″ |
| Average increase ........... | 1 | .... | 3.7′ | ... | 7.4′ | 3.1″ | 10.6′ | 4.3″ |
| *Pinus jeffreyi* (43 trees) ...... | 1 | 6.0′ | 10.2′ | 2.4″ | 15.6′ | 4.9″ | 25.5′ | 7.2″ |
| Average increase ........... | 1 | .... | 4.2′ | ... | 5.4′ | 2.5″ | 9.9′ | 2.3″ |
| *Cedrus deodara* (18 trees) ..... | 2 | 4.0′ | 7.6′ | 1.1″ | 13.4′ | 3.2″ | 26.2′ | 7.2″ |
| Average increase ........... | 2 | .... | 3.6′ | ... | 5.8′ | 2.1″ | 12.8′ | 4.0″ |
| *Libocedrus decurrens* (3 trees). | 2 | 4.0′ | 8.8′ | 2.5″ | 13.7′ | 5.3″ | 25.3′ | 11.3″ |
| Average increase ........... | 2 | .... | 4.8′ | ... | 4.9′ | 2.8″ | 11.6′ | 6.0″ |
| *Pinus coulteri* (16 trees) ...... | 2 | 11.0′ | 15.8′ | 7.8″ | 22.6′ | 12.1″ | 33.3′ | 18.4″ |
| Average increase ........... | 2 | .... | 4.8′ | ... | 6.8′ | 4.3″ | 10.7′ | 6.3″ |
| *Pinus jeffreyi* (11 trees) ...... | 2 | 10.0′ | 8.0′ | 2.0″ | 12.5′ | 4.8″ | 23.3′ | 9.6″ |
| Average increase ........... | 2 | .... | —2.0′ | ... | 4.5′ | 2.8″ | 10.8′ | 4.8″ |

*Note:* Diameter was taken at 4½ feet from ground. All of the above species have produced seed containers but no fertile seed has been recovered to date.

It is 35 years since this experiment was first started and a critical examination of the results obtained is now in order. Average growth made by the species listed compares favorably with growth made by the same species under optimum conditions in their natural habitats.

From the results obtained it would appear that Forester Hosmer's experiment has proved that valuable timber trees will grow on the upper slopes of the higher mountains of the Territory. As to whether timber production will ultimately prove economical it is difficult to say.

# Insects Carried in Transpacific Airplanes

## A Review of Quarantine Work Prior to December 7, 1941

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By C. E. Pemberton

*Transpacific airplane service, with Honolulu one of the principal ports of call, has, in point of time, brought Hawaii close to tropical lands densely populated with many thousands of species of insects not in the Islands today. Quantities of these could live in the Territory and be injurious, and many could ruin our important agricultural crops or seriously affect human health. A brief historical account is given of the efforts made to block this constant menace and to emphasize the magnitude of the problem.*

During March 1936 the Pan American Airways inaugurated regular transpacific airplane service between San Francisco and Manila with stops at Honolulu (Pearl City), Midway, Wake, and Guam. These flights continued through November 1941 and during the latter half of this period Hongkong was included in the itinerary. In addition to this route the Pan American Airways expanded their business early in July 1940 to include regular flights between San Francisco and New Zealand, via Honolulu, Canton Island, New Caledonia, and later Fiji. An average of three to four planes made a round trip from San Francisco over one or the other routes monthly, with stops both ways at each point mentioned in their line of travel.

Beginning on March 6, 1936 and continuing until the outbreak of the present war every plane, without exception, that stopped at Pearl City was boarded by a representative of the Anti-mosquito Control Committee, Chamber of Commerce of Honolulu, or, in 1941, an inspector of the U. S. Public Health Service, to search for and collect all insects, dead or alive, occurring in these planes. Inspectors were permitted to enter the planes prior to the release of the passengers, crew, and baggage and a hasty search was first made for living insects after which a more leisurely inspection was made for dead specimens. In this work there was close cooperation with U. S. Customs officers and plant inspectors of the Territorial Board of Agriculture and Forestry, who had access to passengers' baggage and freight which had been removed from the planes at the airport office. The Pan American Airways Company also cooperated freely.

To comply with the requirements of the U. S. Public Health Service, especially with respect to the transport of living mosquitoes, these planes were sprayed with pyrethrum extract (the normal "Flit" of the time) shortly before landing at each port and also prior to departure at all stations where they stopped. This was a duty assumed by Pan American operatives on each plane.

All insects collected at the Pearl City port, from the date of the first inspection until the beginning of the war, were submitted to the entomologists of the Hawaiian Sugar Planters' Experiment Station for identification.

As the work progressed it became evident to the entomologists that the risk of new insect pests gaining entrance to Hawaii existed in fact. Since the planes came from, or stopped at, regions where serious insect pests of sugar cane occurred which

*THE HAWAIIAN PLANTERS' RECORD,* Vol. 48, No. 3, 1944 (Copyrighted).

were not in the Hawaiian Islands, Dr. H. L. Lyon, Director of the Experiment Station, H.S.P.A., proposed the establishment by the Hawaiian Sugar Planters' Association of a quarantine station at Midway Island and later at Canton Island. This met with the full approval of the Pan American Airways Company and all others concerned. Accordingly, on November 25, 1936, the H.S.P.A. sent an entomologist to Midway. His principal assignment was to inspect and spray all planes immediately upon arrival. All insects, dead or alive, were collected and each month sent to the Experiment Station entomologists in Honolulu for identification. The planes were again inspected before departure from Midway. On April 16, 1940, with the inauguration of regular Pan American service to New Zealand, a similar station was established on Canton Island and the H.S.P.A. maintained an entomologist there also for the same type of work. The salaries of these men were paid by the Hawaiian Sugar Planters' Association, and the Pan American Airways Company cooperated in all necessary ways by furnishing board and lodging, transportation, etc. During the entire period under discussion not a single plane stopped at either Midway or Canton without attention by an H.S.P.A. entomologist. When an employee was at any time relieved of duty because of resignation, vacation, or other cause, entomologists on the regular staff of the Experiment Station at Honolulu were available to fill the gap until the special men for the Canton and Midway stations were replaced or had returned to duty. This happened several times and F. X. Williams, R. H. Van Zwaluwenburg or F. A. Bianchi kept the position filled on one or the other island each time such an emergency occurred.

It is of interest that planes from Honolulu, enroute to the south and west were also treated at Canton and Midway as a means of protection to outside islands and countries against pests in Hawaii not already in those regions.

Canton and Midway Islands thus became, in a sense, insect filters through which all planes passed before reaching Honolulu and later California. This work supplied a definite safeguard to Hawaii and the mainland against oriental and South-Sea pests dangerous to agriculture, horticulture, ornamental plants, and the health of man and domestic animals. It is the ideal form of quarantine since both Midway and Canton Islands are small coral islets with an extremely limited fauna and flora.

The record of insects taken from planes at Honolulu, Midway, and Canton is one of definite reference value, since it tells what is entering the planes at the various ports, and to what extent living forms are transported from one country to another. The great development of air transport over the Pacific since the beginning of the war has increased tremendously the number of insects carried to Honolulu from far distant places. The task of identifying these insects by the H.S.P.A. entomologists continues and the record has grown to imposing proportions. The following summary covers the record from March 6, 1936 to the end of November 1941. Though the quantity of material taken from planes since the war began greatly exceeds the collections from 1936 through 1941, the record for individual planes today remains approximately the same as that for pre-war planes.

During 1941 a number of the planes cited below were listed by the inspectors as "Bombers."

## PLANES OUTWARD BOUND

March 19, 1936 to December 3, 1941

| | |
|---|---|
| No. Planes Arriving at Honolulu from California | 321 |
| No. Insects Removed and Identified | 1,367 |
| No. Insects Found Alive | 137 |
| No. Mosquitoes Found in Planes | 88 |
| No. Mosquitoes Alive | 7 |

### Records of Special Interest

*Anopheles pseudopunctipennis:* A living female of this mosquito was taken from a plane listed as a "Bomber" on October 21, 1941. In Herms' "Medical Entomology" it is listed as an important vector of malaria in parts of South and Central America and Mexico. The mosquito occurs throughout California according to Herms but is of no consequence in California as a carrier of malaria.

*Culex pipiens:* A mosquito not known in the Hawaiian Islands. A total of 40 was taken from the planes arriving at Honolulu during this period, five of which were alive.

*Theobaldia incidens:* This mosquito was taken from planes on four occasions, a single specimen each time and in one case the individual was alive. This is a common domestic species in California but does not occur in Hawaii.

*Culex tarsalis:* On two occasions a single individual was taken from a plane, both being dead. This mosquito is not in Hawaii.

*Pulex irritans:* This common flea was taken from planes alive several times. This is of interest only to the extent that sprays evidently do not normally reach or kill them in planes.

*Diabrotica soror:* Three times during the period under discussion this notorious defoliator of many kinds of plants was taken from planes and in one case it was found alive. This beetle does not occur in Hawaii.

*Glyptina cerina:* Known as the potato flea beetle and not in Hawaii. A living specimen was taken from a plane on November 9, 1941.

Flies representing many families occurred most frequently in the planes.

## PLANES HOMEWARD BOUND

March 19, 1936 to December 3, 1941

| | |
|---|---|
| No. Planes Arriving at Honolulu from Hongkong or Manila via Guam, Wake, and Midway Islands, or from New Zealand via New Caledonia, Fiji, and Canton Island | 301 |
| No. Insects Removed at Canton, Midway, and Honolulu and Identified | 10,081 |
| No. Insects Found Alive | 2,067 |
| No. Mosquitoes Found Dead | 207 |
| No. Mosquitoes Found Alive (*Culex quinquefasciatus*) | 4 |

*Note:* In the above total of 2,067 insects found alive, all but 228 were detected and removed from the planes by inspectors stationed at Canton and Midway Islands. Of the 228 taken alive from planes after arrival at Honolulu, 206 of these were insects common in Hawaii, many of which could have entered the planes after arrival at the Hawaiian port while inspection was underway. Many of these were common flies and 88 of them were ants which could be sufficiently concealed in lunch packets and other baggage to escape spray treatment. Thus during the five and one half years of operation of the Midway and Canton Island insect quarantine work, only 22 living insects not known in Hawaii were found in planes arriving at Honolulu from the South or the Orient.

### RECORDS OF SPECIAL INTEREST

*Aedes vigilax* and *Culex sitiens:* These two mosquitoes have been taken dead from planes a number of times. They breed in brackish water. The former is a vicious biter. Neither species occurs in Hawaii.

*Anopheles litoralis:* Though not considered a vector of malaria in the Philippines, this mosquito has been found dead in planes upon their arrival at Midway several times. The mosquito breeds in brackish water. Not in Hawaii.

*Aedes vexans:* This mosquito has been found dead in planes a number of times. Being a vicious day biter, with a wide distribution in the tropics, it is fortunate that it has not become established in Hawaii.

*Anomala sulcatula:* This beetle has reached Midway alive in planes from Guam. It is a member of a highly undesirable genus of beetles whose grubs are destructive to plant roots.

*Prodenia litura:* A moth occurring around the tropic world but not in Hawaii. The caterpillars of this insect are highly destructive to a large number of economic plants, including banana, taro, cotton, sweet potato, tomato, cabbage, lettuce, etc. It has been taken both alive and dead from planes several times.

*Nephotettix apicalis:* A pest of rice. Large numbers of this night-flying leafhopper have been taken from planes from the Philippines and Guam. They have been found alive in planes arriving at Midway. Not in Hawaii, nor in California where the rice industry is a large one.

As in the case of the outward-bound planes, a large proportion of the insects taken from planes at Midway, Canton, or Honolulu was flies.

# Weed-spray Studies—II*

By R. J. Borden

A follow-up of the studies in weed control, which were reported in *The Hawaiian Planters' Record,* 48: 21–29, 1944, has confirmed some of the earlier results and added a few more which are presented in the accompanying set of photographs with a few brief comments.

Because the earlier study had indicated a satisfactory kill of "wire grass" (*Eleusine indica*) at two, four, six, and eight weeks of age when "Conc. 40" was used in a 1-to-20 dilution, but an unsatisfactory kill when the dilution was 1-to-80, we were concerned with finding whether an intermediate dilution might be satisfactory. Also, because a difference of opinion existed as to the relative difficulty in controlling wire grass with "Conc. 40" as compared with "kukaipuaa" (*Digitaria spp.*), both of these weeds were included.

The treatments consisted of "Conc. 40" in dilutions of both 1-to-20 and 1-to-40 sprayed so as to thoroughly wet the foliage which had developed by the second, the fourth, and the sixth week after the weed seeds were started. Fig. 1 shows the amounts of growth for both grasses at the time the herbicide was applied.

The effects from spraying were definite and quite rapid (less than 24 hours), especially where the 1-to-20 dilution had been used and on the younger weed growth. To determine the completeness of the kill, however, the flats carrying the weeds were given good growing conditions for two more weeks before the final photographs and counts for the percentage of kill were made. Thus in Figs. 2 and 3 we have pictures of a representative flat of each treatment, taken two weeks after the applications of herbicide had been made.

The kill of wire grass (Fig. 2) by the 1-to-20 dilution was 100 per cent at all three stages of growth. With the weaker 1-to-40 dilution, however, the kill was only 64 per cent on the older six-week growth, 70 per cent on the four-week-old growth, and 75 per cent on the young two-week-old weeds.

On the kukaipuaa (Fig. 3) the 1-to-20 dilution was also 100 per cent effective at all three growth stages, whereas the kill from the 1-to-40 dilution was only 45 per cent on the older weeds, 80 per cent on the four-week-old growth, but 96 per cent on the youngest weeds.

The differences in the kill of these two weed species by the 1-to-40 dilution are of interest. Apparently the younger growth of kukaipuaa was more susceptible than the corresponding growth of wire grass, whereas it was somewhat more difficult to get a satisfactory kill of the six-week-old kukaipuaa than of wire grass of the same age. This is perhaps due to the fact that the more recumbent growth habit of the kukaipuaa, as it gets older, makes it very difficult to penetrate the leafy mass with the spray solution, whereas the more erect stems of the wire grass can be more completely wetted.

With both weed species some individual plant tolerance to the more dilute herbicide as used was again found. When the plants were being sprayed, special care was taken to see that all visible foliage was thoroughly wetted. In spite of this precaution some individual plants were not killed.

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* Project A 105—No. 83.2.

Records of the amounts of spray solution that were required to wet adequately the foliage show that the four-week-old weed growth required four times the quantity needed by the two-week-old weeds, and that the six-week-old weeds required eight times as much as the young two-week-old plants.

These results lead us to re-emphasize the fact that a delay in spraying results in inefficiency. Early spraying gives the best control and uses the least material, for once the weeds have formed more than four or five leaves, it will be difficult to kill them except with more concentrated herbicides. So, when spraying is delayed, not only must the concentration of the herbicide be stepped up, but the total quantity used must be increased, and both such increases involve a greater likelihood of injury to the cane crop itself.

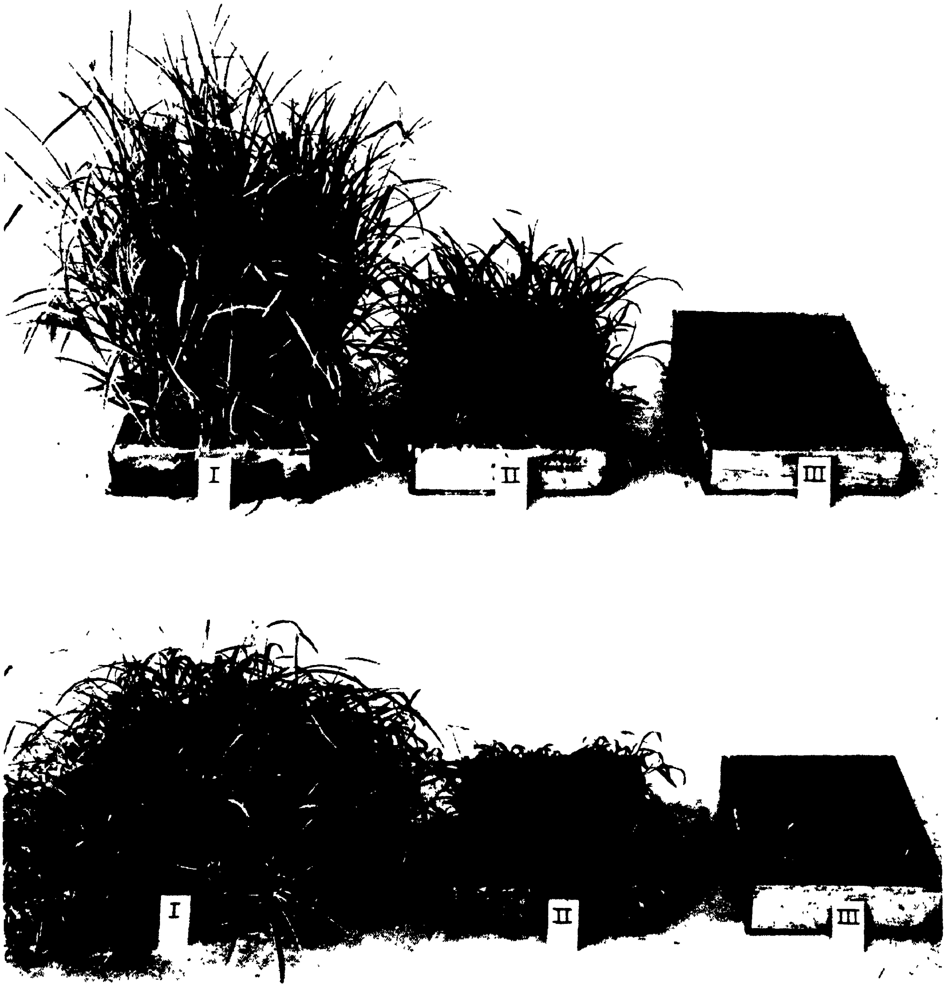


Fig. 1. Weed growth at time of spraying:
I—6-week-old growth. II—4-week-old growth. III—2-week-old growth.
Upper: Wire grass. Lower: Kukaipuaa.

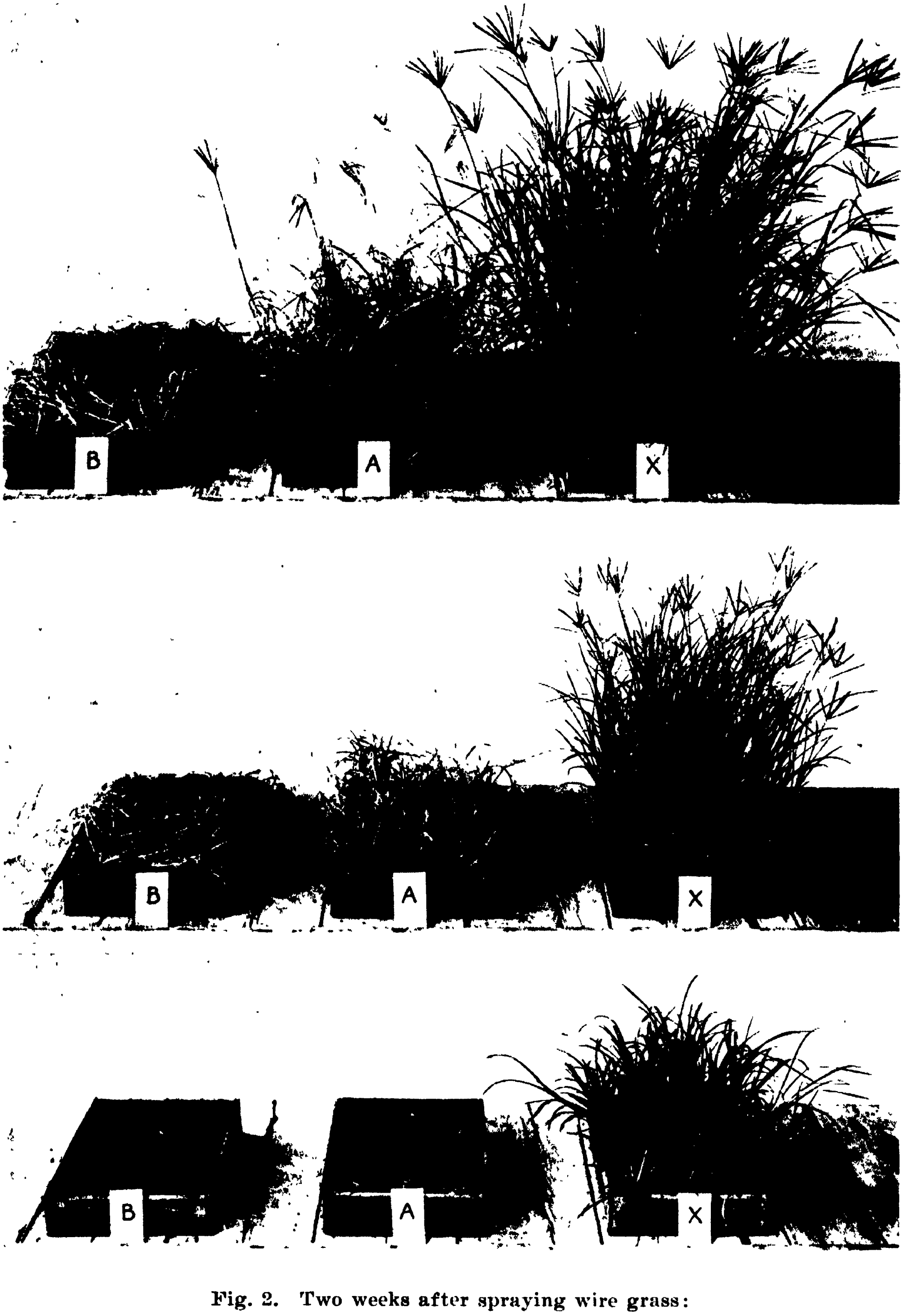


Fig. 2. Two weeks after spraying wire grass:
X—With tap water only.
A—With "Conc. 40" at 1-to-40 dilution.
B—With "Conc. 40" at 1-to-20 dilution.
Age when sprayed: Upper—6 weeks; center—4 weeks; lower—2 weeks.

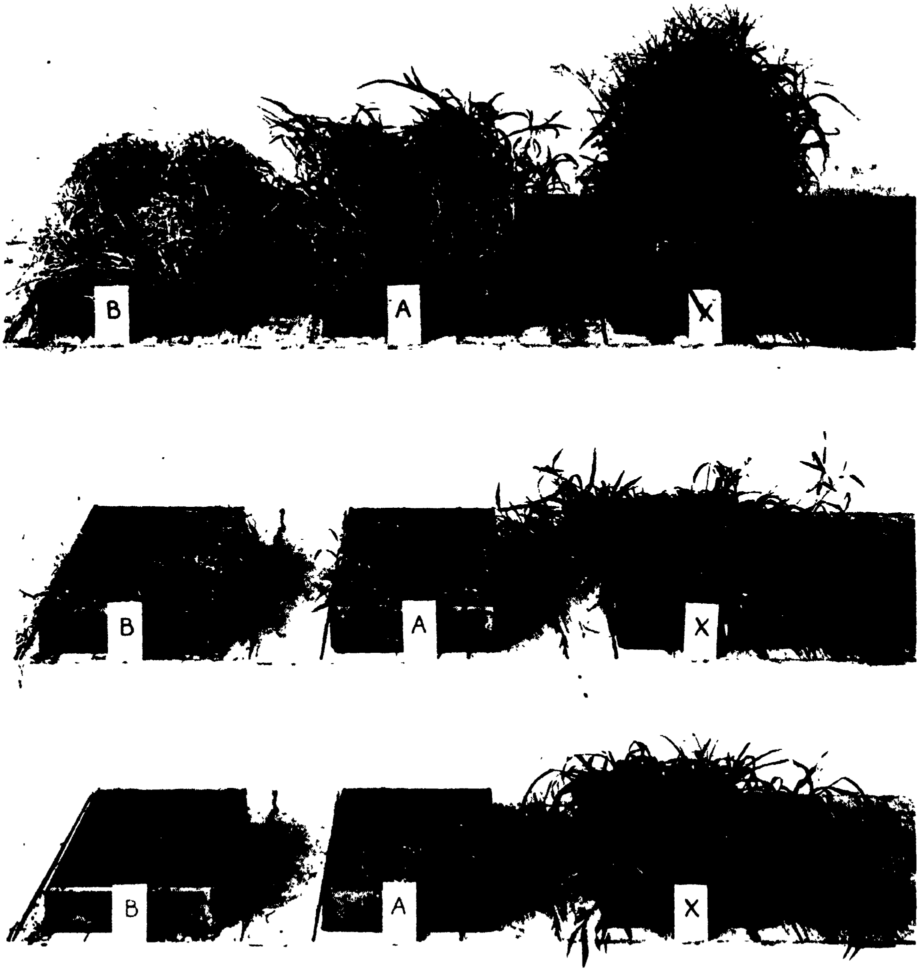


Fig. 3. Two weeks after spraying kukaipuaa:
X—With tap water only.
A—With "Conc. 40" at 1-to-40 dilution.
B—With "Conc. 40" at 1-to-20 dilution.
Age when sprayed: Upper—6 weeks; center—4 weeks; lower—2 weeks.

# Chemical Control of Hardy Weed Grasses

## (A Discussion)

By Francis E. Hance

*Tough, wiry grasses are supplanting the more rapidly destroyed succulents and annuals in many Hawaiian cane fields. A discussion is presented suggesting a means of meeting this situation in the current research devoted to the weeding problem.*

Over a period of years a continuous program of chemical spray treatment of sugar cane field weeds results in the disappearance of succulent, annual, broad-leafed weeds, and the survival of the more resistant grasses.

The present Hawaiian practice of weed control does and will destroy, for a limited time, most all above-ground weed growth regardless of age, *provided the weeds are actually wetted.*

Our spraying practice destroys most of the tender succulents and all of the bushy annuals. Going down with them temporarily, as burned blades, are the predominating fractions of most cane field weeds—grasses. An area adequately sprayed at this point gives the appearance of a chemical weeding job that has been very well done. Actually the job is not well done because the readily destroyed succulents and annuals have been removed for the season and in the course of a few weeks their place will be taken by the oncoming grasses which will be found budding vigorously and rapidly from the soil side areas of every "dead" grass crown in the field. Such a weeding practice is but a compromise because it expands the grassy coverage and encourages the growth of the very weed types which are the most difficult to eradicate.

Even were labor available to substitute hoeing for the toxic chemical sprays the net result would be essentially the same.

Agricultural literature describes chemical weeding operations on the mainland which frequently appear promising and encouraging. Circulars and advertisements issued by chemical herbicide manufacturers often give glowing accounts of phenomenally effective spray chemicals. In almost all cases such claims are reasonably correct and fittingly proper when assessed against field conditions, the type of weeds, and among the crops where they are used. In running down a promising lead we frequently find that a given herbicide will, at low concentration and in one application, utterly destroy all the weeds in a field of grain or vegetables and scarcely or not at all injure the main crop. As a rule the herbicide will be a non-poisonous compound and comparatively easy to procure. Time after time it develops, at this point, that the weeds referred to are entirely of the broad-leafed variety (hence readily destroyed) and the crop not injured by the herbicide is a member of the grass family (pasture, wheat, barley, corn, etc.). Obviously we get little to bolster our weeding program from a herbicide of this character. However, this is not always the case.

A. S. Crafts and H. G. Reiber (2), for instance, in discussing the toxicity of certain petroleum oils to plant life differentiate between the prompt chemical effect of herbicides upon plant tissues with which they come in contact and the slower, penetrating effect of certain oils, or emulsions of oils, beyond the points of contact and extending, in the cases of some grasses, to the region of the crown and even below that part of the grass crown at the soil surface. The penetrating effect they describe, if found sufficiently lethal toward Hawaiian grasses, suggests a lead which should be thoroughly investigated.

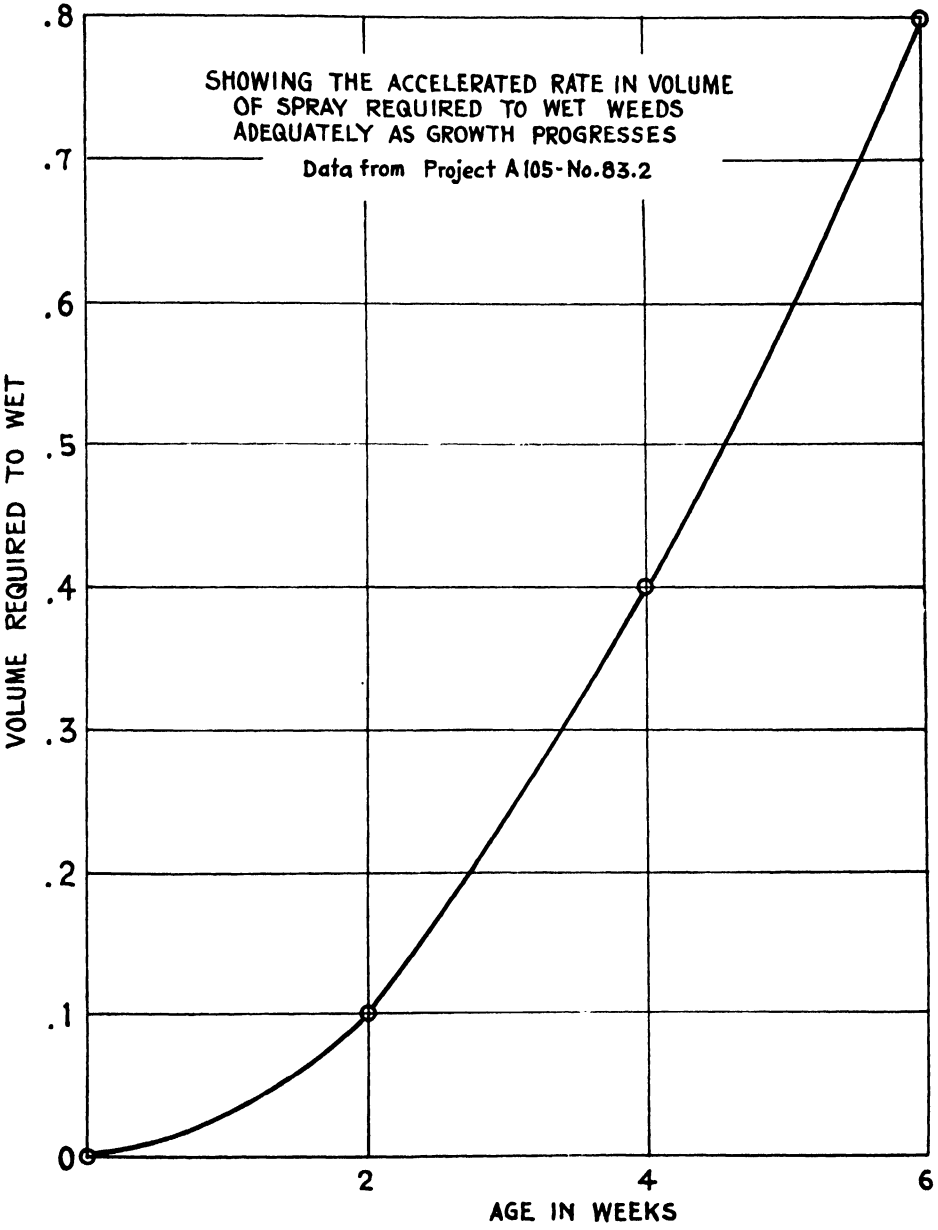
In another discussion Crafts (3) describes experimental studies in which oil-soluble amendments were incorporated with petroleum oils in order to fortify them to the point where the treated oil would remain effective even under high dilution or as an emulsion with water. He found three outstanding fortifying agents: dinitro ortho cresol, pentachlorphenol, and dinitro ortho secondary butyl phenol.

Using a formula containing ½ per cent pentachlorphenol in a six per cent Diesel-oil emulsion he secured rather encouraging results. He states that this formula proved sufficiently toxic to coarser grasses to provide adequate fire strips along highways. *When applied in sufficient volume to cover the vegetation completely* it killed everything except wild oats and barley in the early heading stages. It did kill crowns and basal portions of the stems which it affected so that the plants died completely in a period of 20 days. However, barley plants survived two sprayings of this mixture.

If Crafts' discussion has been correctly understood it appears that increased toxicity secured by fortifying oil emulsion grass sprays is not desirable after all. He suggests that ⅛ per cent dinitro secondary butyl phenol will replace the ½ per cent pentachlorphenol in the above formula, although, he adds further that by increasing the butyl phenol compound to ¼ per cent or more a more toxic mixture may be obtained *but even this increased toxicity may not be of any avail in killing large vigorous grass plants.*

We gather from Crafts' description of his research studies that, rather than depend on a highly toxic amendment to a contact herbicide, a superior effect may be realized on grasses by utilizing the slower penetrating toxicity of certain petroleum fuel oils, and thus reach the stems and even the crowns to a distance of several inches from the portion of the plant actually sprayed. He cites the effectiveness of water-and-oil emulsions as a substitute for straight oil applications, but notes the disadvantage of an ordinary emulsion of this type which necessitates providing the spray tank with an agitator. He does not lean entirely aside from aqueous solutions of herbicides, however, for he reports satisfactory control of grasses using ½ per cent of the ammonium salt of dinitro ortho secondary butyl phenol with an effective wetting agent.

In an article appearing directly ahead of this paper, R. J. Borden (1) reports that, when a measurement was made of the requisite volume of spray solution required to wet adequately the weed foliage in an experimental study, it was found that a volume sufficient to cover a two-week-old grass growth had to be increased four times for an identical stand of the same type of grass at double this age, and eight times the two weeks volume under comparable conditions upon a stand at triple the two weeks age. In a graph, Borden's data illustrate in a spectacular manner the rapidly accelerating rate at which the volume of spray solution must be increased to keep pace with advancing weed growth beyond the tender shoot stage. The implications are obvious as to efficiency of lethal dosage and economy of labor, equipment and chemicals. The graph is shown herein.



Facts accruing from observations in the field and in the literature may be summarized as follows:

1. Our presently employed spray solutions are "contact" herbicides.
2. A contact spray destroys only that portion of the weed which it wets.
3. The time to spray is immediately following the appearance of young, tender, weed growth.

4. Spray solution striking bare soil will not destroy germinating weed seeds directly beneath the soil surface, nor the young plants which will follow later.

5. Wetting agents or spreaders are essential in most spray solutions to insure uniform wetting of grass blades or waxy leaf surfaces.

6. Combinations of the H.S.P.A. Activator and sodium chlorate in water *do not* require the addition of a wetting agent.

7. Increasing the concentration of lethal substance in a contact spray above that just required to destroy above-ground portions of the plant will not in any manner contribute to a better or more lasting kill, nor will it ordinarily reach the root systems of tough grasses or the embryo growing points just under the crown.

8. Herbicide compounds used extensively on the mainland for destroying broad-leafed weeds and annuals in grain fields—without damage to the main crop—are of little value on Hawaiian cane lands.

Further research studies in weed control by the Chemistry department of the Experiment Station are planned to be conducted somewhat as follows:

1. The combining of low concentrations of our present lethal agents with graded amounts of penetrating oils (described elsewhere) in an effort to destroy or weaken above-ground portions of grasses and at the same time reach the stem and under-crown area with the penetrant oil plus the lethal substance combined with it.

2. The double objective in No. 1 implies a single spray application of a fairly stable emulsion *on young grass.* It is conceivable that on older grasses additional applications of the emulsions must be made if the stems and crowns are to be reached. These points are to be studied.

3. Explore as fully as possible all available oily penetrants which may prove effective in controlling grasses and which may be applied as a spray with existing equipment.

4. Determine by field trial the value of newly proposed "non-poisonous" herbicides under Hawaiian conditions.

5. Endeavor to develop a type of oil-water emulsion which will not break for an hour or longer and which will carry other essential constituents toxic to hardy grasses. This objective, if realized, will eliminate the complication of agitation of spray emulsion during its application.

## LITERATURE CITED

(1) Borden, R. J., 1944. Weed-Spray studies—II. The Hawaiian Planters' Record, 48: 187–191.

(2) Crafts, A. S., and Reiber, H. G., 1944. Toxicity of oils to carrots and weeds. A mimeographed paper issued by the Divisions of Botany and Chemistry, College of Agriculture, University of California (April), 3 pages.

(3) ————, 1944. Experiments on general contact herbicides. A mimeographed paper issued by the Botany Division, College of Agriculture, University of California (May), 6 pages.

# Nitrogen Efficiency

By R. J. Borden

*Under conditions of all-year-round growth, where crops of sugar cane are being started almost every month of the year, we often find nitrogen fertilizer applications being made (weather permitting) without serious regard to the so-called seasonal conditions that are likely to prevail immediately thereafter. These conditions apparently can have a considerable influence on the amount of nitrogen absorbed and its subsequent use by the crop.*

*The results which are here discussed show that a more complete uptake of nitrogen and greater yields by an indicator crop have followed nitrogen applications that were made in May and August than from similar amounts applied in February or in November. Thus the efficiency of the nitrogen fertilization has been definitely influenced by as yet unidentified seasonal effects.*

Although the sugar cane areas in Hawaii do not have extreme ranges in climatic conditions, there are some differences in temperature and sunshine, and in wind, humidity and rainfall intensity which probably have their combined direct and indirect effects on yields, and one of our previous studies* has already definitely established the dominating effect of climate upon cane and sugar yields. Hence, inasmuch as the major changes or differences in climate form the basis for the divisions of the year into seasons, we would expect the seasonal differences to also have a large influence on yields.

*The Plan:*

In an effort to find the seasonal effects on the response to be obtained from nitrogen applications, we have completed the first five years of a study† with this objective. For this study we prepared a well-mixed stock of a Manoa soil in October 1938 and on the first of November, February, May, and August during each year since this date we have planted a series of 24 Mitscherlich pots with an indicator crop (*Panicum barbinode*). As far as possible each series has been grown under as nearly identical conditions for development as could be provided, except for the following eight differentials in nitrogen fertilization which were added to the soil as ammonium nitrate at the time of planting:

No. 1—Control, no N.
No. 2—0.275 gm. N/pot
No. 3—0.55 gm. N/pot
No. 4—0.825 gm. N/pot
No. 5—1.1 gms. N/pot
No. 6—1.375 gms. N/pot
No. 7—1.65 gms. N/pot
No. 8—2.2 gms. N/pot

Each indicator crop has been harvested at 90 days after planting and we have secured at each harvest (1) the total dry weight from each of the three replicated pots of each treatment, and (2) the total nitrogen content from a composited sample of these dry weights. From these data we have calculated the differences between the total grams of nitrogen as found in the crop from the control (no N), and the total in each crop from each of the seven treatments which received the nitrogen fertilizer; these differences have then been expressed in terms of the per cent of nitrogen added which was recovered.

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* A 105—No. 43.

† A 105—No. 104.01.

### *Effect on Yields:*

The data which have been secured have been studied to find the effect, on the total dry weights harvested, that was produced by each of three main factors, namely: (1) *amounts* of nitrogen applied, (2) *year* during which crop was grown, and (3) *season** of year in which the growth took place and by their first-order interactions. An analysis of variance has established the degree of significance of these effects, and we have identified a dominant and independent effect for each of the three main factors over any of their interactions. Hence we can limit our summary and discussion to these main effects which are shown in Table 1.

TABLE I
SUMMARY OF 3 MAIN EFFECTS ON YIELDS
Grams Total Dry Weight Harvested

1—From amounts supplied
(for all years and seasons)

| Gms. N supplied | Avg. gms. dry wt. |
|---|---|
| 0 | 47 |
| .275 | 119 |
| .55 | 183 |
| .825 | 239 |
| 1.1 | 267 |
| 1.375 | 295 |
| 1.65 | 319 |
| 2.2 | 337 |
| M.d.r. | 9 |

2—In different years
(for all amounts and seasons)

| Year | Avg. gms. dry wt. |
|---|---|
| 1939 | 221 |
| 1940 | 214 |
| 1941 | 208 |
| 1942 | 229 |
| 1943 | 257 |
| M.d.r. | 7 |

3—In different seasons
(for all amounts and years)

| Season | Avg. gms. dry wt. |
|---|---|
| Winter | 152 |
| Spring | 203 |
| Summer | 275 |
| Fall | 273 |
| M.d.r. | 6 |

M.d.r. = minimum difference required for odds of 19 to 1.

Increasing the amounts of nitrogen has resulted in the increases in dry weights which were more or less expected. Yields from the different years showed some fluctuation but the low average for 1941 was only 19 per cent less than the high average for 1943. But our chief interest in these summaries lies in the effects produced by the different seasons, for it is doubtful if their relative effects on yields have heretofore been as adequately established. Thus we find that yields from the indicator crops which were grown during the winter and spring were only 55 and 74 per cent respectively of the averaged summer-fall crops in spite of the fact that a uniform and comparable treatment was given for five years of cropping in all seasons.

A good idea of the specific effects from different seasons upon the dry weights as harvested from the different nitrogen treatments may be obtained from Fig. 1.

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* For convenience, the following seasonal identities have been used:
Winter—for the crops started November 1 and grown during the next 90 days.
Spring—for the crops started February 1 and grown during the next 90 days.
Summer—for the crops started May 1 and grown during the next 90 days.
Fall—for the crops started August 1 and grown during the next 90 days.

Here we note: (1) The similarity of the yields which resulted from identical amounts of nitrogen supplied for the summer- and fall-grown crops, and their general level above the average for all seasons; (2) a curve of dry weights from spring-grown crops which is definitely below this average; and (3) still lower levels for the yields from the winter crop.

*Nitrogen Efficiency:*

The figures in Table II are those for the average grams of dry weight produced per gram of nitrogen supplied—a good measure of nitrogen efficiency.

TABLE II
EFFICIENCY OF APPLIED NITROGEN

| Grams N applied | Grams dry wt. per gram N | | | | Average for amounts applied |
|---|---|---|---|---|---|
| | Winter | Spring | Summer | Fall | |
| .275 | 305 | 382 | 513 | 535 | 409 |
| .55 | 229 | 295 | 398 | 411 | 333 |
| .825 | 195 | 256 | 354 | 356 | 290 |
| 1.1 | 164 | 220 | 297 | 289 | 243 |
| 1.375 | 144 | 195 | 264 | 255 | 215 |
| 1.65 | 129 | 175 | 235 | 233 | 193 |
| 2.2 | 99 | 142 | 190 | 182 | 153 |
| Average of seasons | 181 | 238 | 322 | 323 | |

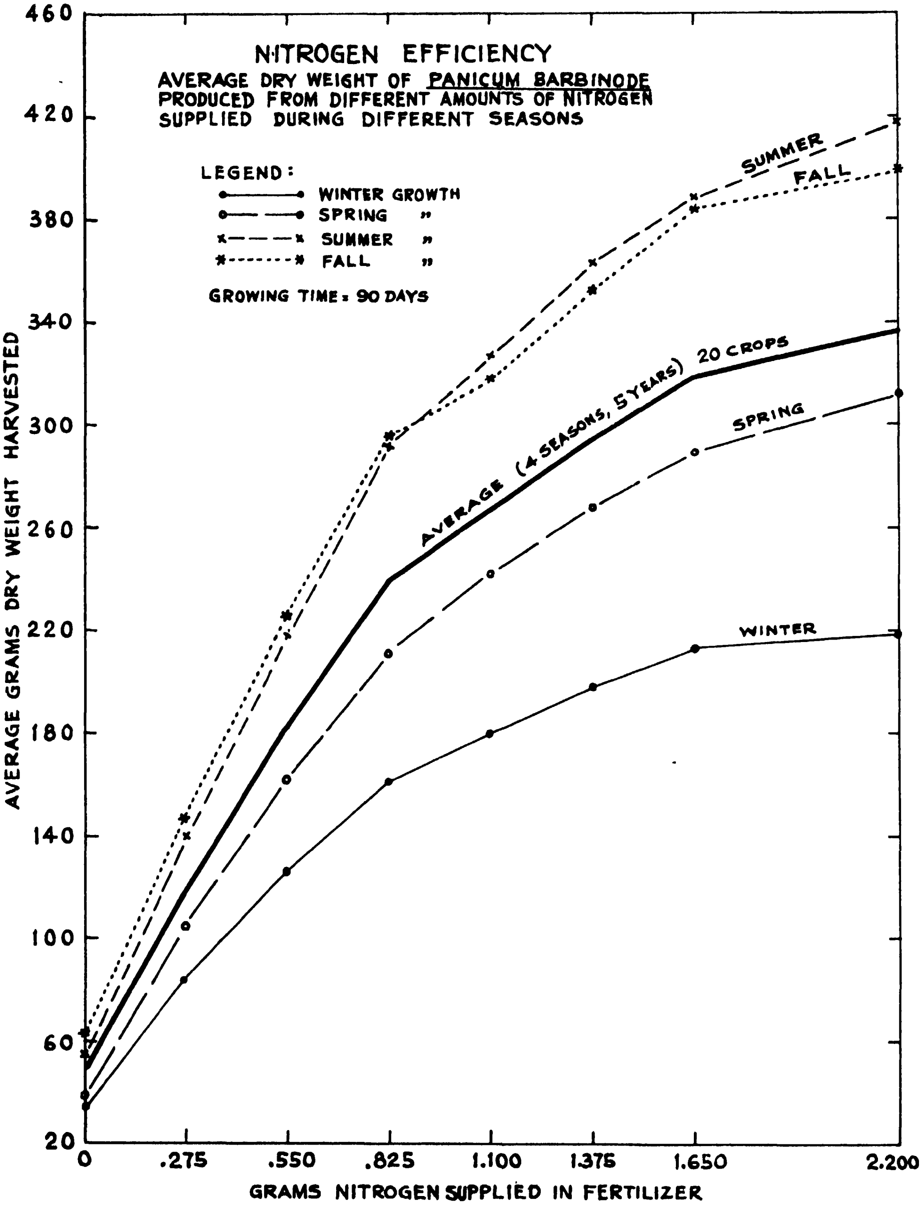
For each additional amount of nitrogen supplied there is the corresponding decrease in efficiency that is usually associated with all growth factors, *i.e.*, the law of diminishing returns is operative; this is true regardless of the season during which the crop was grown.

Differences in seasonal effects are quite clear. Thus one gram of nitrogen supplied for summer and fall growth produced an average of 322–323 grams of dry weight as compared with an average of 238 grams from spring growth, and of only 181 grams of winter growth.

A few examples from the graphs on Fig. 1 will further emphasize the difference in the nitrogen efficiency that was obtained during different seasons. For instance: an application of 0.55 gram N produced an average yield from 20 crops of 183 grams. Reference to the several curves and their axes in Fig. 1 will show that an equivalent yield would be expected from crops grown in summer and fall when supplied with only 0.41 gram N (25 per cent less N) but that an equivalent yield from spring-grown crops would probably need 0.69 gram of N (25 per cent more) and, furthermore, that this average 0.55-gram application would need to be more than doubled to produce an equivalent yield in winter.

From another viewpoint the curves in Fig. 1 show that 1.1 grams N have produced an average of 323 grams of total dry weight from summer and fall applications. This same amount of nitrogen applied in spring was able to produce only 242 grams, and only 180 grams when it was supplied in winter. Thus, if it were deemed necessary to provide 1.1 grams N in summer and fall in order to get a desired yield, this amount would be excessive and wasteful for applications in spring and winter when even double the amount (2.2 grams) has failed to produce an equivalent dry weight.

Still another angle to emphasize this point can be shown from Fig. 1. The maximum yield secured from the winter crop was 218 grams, and this was the result



from the 2.2-gram application of nitrogen. This same amount of dry weight could have been produced by approximately 0.9 gram N or 60 per cent less nitrogen applied in the spring, and by approximately 0.5 gram N or 80 per cent less nitrogen applied in the summer and fall.

Thus the evidence seems quite clear that there will be differences in nitrogen efficiency, *i.e.*, its ability to affect yields, which will be due to the differences in the seasonal conditions that prevail during the next few months after the nitrogen fertilizer is supplied. That this difference in efficiency is in turn due to a difference in the probable nitrogen uptake and recovery by the growing crop is strongly suggested by the subsequent discussion.

*Nitrogen Recovery:*

The nitrogen recovery figures reported hereafter have reference to the total nitrogen found in the total vegetative growth (except roots*) produced by each treatment in a period of 90 days. Previous studies have shown that 90 days are adequate for the complete exhaustion of applied nitrogen from soil potted and cropped as in the present study. Moreover, an analysis of this soil showed an absence of available nitrogen (by R.C.M.) at harvest, and subsequently the total amount of available nitrogen found was never more than 0.0008 per cent. Thus we can assume a reasonably complete depletion of the available nitrogen from the cropped soils. Furthermore, losses of nitrogen by leaching were avoided by the use of drainage pans and the return of all leachates when the pots were irrigated. So it seems quite safe to imply that the percentage nitrogen recoveries that we have recorded at least represent the trends from the effects indicated.

An analysis of variance of the nitrogen recovery figures shows: (1) a significant and independent effect from the different amounts of nitrogen supplied in the fertilizer upon its subsequent recovery in the crop grown; (2) an effect of the year in which the crops were grown, which effect was however differently influenced by the season of the year concerned; and (3) a highly significant and wholly independent effect of the four seasons during which the crops developed. Interactions between amounts and years, and between amounts and seasons were not significant.

A summary of the three main effects and of their only significant interaction (years X seasons) is given in Table III.

TABLE III

SUMMARY OF 3 MAIN EFFECTS ON NITROGEN RECOVERY

Percentage of Nitrogen Added That Was Recovered

1—From amounts supplied

| Gms. N supplied | Avg. % recovered |
|---|---|
| .275 | 78.2 |
| .55 | 79.8 |
| .825 | 81.9 |
| 1.1 | 81.3 |
| 1.375 | 81.5 |
| 1.65 | 83.1 |
| 2.2 | 76.8 |
| M.d.r. | 3.7 |

2—In different years

| Years | Avg. % recovered |
|---|---|
| 1939 | 80.6 |
| 1940 | 84.2 |
| 1941 | 74.8 |
| 1942 | 79.0 |
| 1943 | 83.2 |
| M.d.r. | 3.1 |

3—In different seasons

| Seasons | Avg. % recovered |
|---|---|
| Winter | 64.4 |
| Spring | 76.7 |
| Summer | 92.0 |
| Fall | 88.3 |
| M.d.r. | 2.8 |

SUMMARY OF INTERACTION BETWEEN YEARS AND SEASONS

Average Percentage of Nitrogen Added That Was Recovered

| | Years | | | | |
|---|---|---|---|---|---|
| Season | 1939 | 1940 | 1941 | 1942 | 1943 |
| Winter | 66.0 | 64.0 | 64.3 | 59.8 | 67.8 |
| Spring | 75.6 | 82.8 | 76.3 | 71.8 | 77.3 |
| Summer | 90.9 | 100.4* | 79.6 | 92.5 | 96.8 |
| Fall | 90.1 | 89.6 | 79.2 | 91.9 | 90.9 |

M.d.r. = 6.3 *SE = ∓2.3

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* While we regret the omission of the roots, it is not believed that the relationships involved would be significantly different from those found for the above-ground parts that were harvested and analyzed, for the amounts of dry weight of roots and of the nitrogen therein would be expected to reflect the variations in amounts of nitrogen supplied, and in the effect of years and seasons quite similarly to the top growth. Thus the inclusion of the roots would have increased the actual totals but probably made little difference in the relationships between the several effects that were studied.

The percentage of nitrogen recovered from the different amounts supplied, which were not differentially influenced by the year or season in which the crops were grown, does not vary to any great extent until the highest amount is encountered; this 2.2-gram application shows a somewhat reduced recovery, and thus lends support to previous studies which have also shown lower percentages of nitrogen recovered from the higher nitrogen applications.

Recoveries of nitrogen in the crops grown in 1940 and in 1943 were the highest of the five-year period and were quite similar. However, although the spring and summer crops in 1940 were able to pick up more nitrogen than those in these same seasons of 1939 and 1942, this was not true for the fall and winter crops of these same years. And although 1940 recoveries were in general higher than those of 1941, this was not true for the winter seasons in these two years. The winter crop of 1943 showed a higher recovery than that of 1942 but during the other three seasons of these two years the differences were not significant ones. Comparing the crops of 1943 with 1941, we find higher recoveries for the 1943 crops during the summer and fall only. Comparisons of 1943 with 1939 and 1940 show very similar seasonal recoveries of the applied nitrogen.

The most significant information, however, is that the nitrogen uptake and thence its recovery in the crops that were grown in the summer seasons was more complete than from the fall-grown crops; that recovery from the crops grown in the fall was in turn greater than from those grown in spring; and furthermore that more nitrogen was recovered in the spring-grown crops than in those grown during the winter. These findings point quite definitely to the fact that nitrogen applied for growth during the summer has the best chance of being most fully taken up by the growing crop, and hence it should be more efficient than nitrogen applied at other seasons. Even without the possibility of losses by leaching, the probable recovery of nitrogen from the winter and spring applications seems too low to guarantee full efficiency therefrom.

From these facts, which have been secured from carefully controlled crops of panicum grass, we can perhaps postulate that a crop of sugar cane should get a higher efficiency from summer than from spring applications of nitrogen. Furthermore, if these percentage recovery figures from panicum grass in the different seasons can be considered reasonably valid for sugar cane, we would expect that it would take an application of approximately 70 pounds of nitrogen in winter, or of 60 pounds in spring, to result in an equivalent recovery of nitrogen by the crop from only 50 pounds applied in summer or fall.

# The Recent Introduction of Armyworm Parasites From Texas

By Fred A. Bianchi

*Six species of parasitic wasps were introduced from Texas during 1942–1943 in an effort to obtain further control of* Laphygma exempta *and other related armyworms and cutworms. Two species are known to be established already and some of the others may reasonably be expected to turn up in our fields eventually. The present article is intended to familiarize plantation men with the salient aspects in the life history of the species already established and to alert them in regard to those which have not yet appeared in our fields but may yet show up. In addition, while not intending to forecast the future value of the species concerned, the article presents historical data which should serve to facilitate such an evaluation if it is ever attempted.*

*Laphygma exempta* (Walker), the common armyworm of our cane fields, is of oriental origin and not found on the American continent. Some related moths, however, are of even greater importance in the mainland United States, particularly in the southern areas, than *L. exempta* is in Hawaii. Among them is *Laphygma frugiperda* (S. and A.), the fall armyworm, whose sporadic depredations are likely to extend over nearly two-thirds of the United States and which in habits and appearance is very similar to *Laphygma exempta.* Although the planters of corn or alfalfa may sometimes experience difficulty in believing the fact, this pest is known to be attacked by an imposing list of parasites, without which the depredations of the host would doubtlessly be much more serious than they are. This parasite-complex was studied principally by R. A. Vickery, Bureau of Entomology, U. S. Department of Agriculture, in the Gulf Coast District of Texas during several years beginning with 1910 (*Studies on The Fall Army Worm in the Gulf Coast District of Texas,* Technical Bulletin No. 138, U. S. Department of Agriculture), and it was his findings that led to the choice of Brownsville, Texas, as headquarters for the present writer when in 1942 it was decided to undertake the introduction of additional parasites of *Laphygma exempta* into Hawaii. Observations incidental to other work done in Guatemala in 1932–35 and in 1941 had already shown us the scarcity in Central America of hosts related to *Laphygma exempta* and the probable difficulty of obtaining the desired parasites either there or farther south, so the presence of *L. frugiperda* and its numerous enemies within the U. S. and in reach of quick transportation may be considered a piece of good fortune for the Territory.

Vickery's bulletin, which appeared in 1928, lists eleven primary parasites. To these the present writer was able to add another, a species of *Perisierola,* which was actually reared from *L. frugiperda* in the laboratory. Thus Texas offered the choice of twelve parasites, but we attempted the introduction of only six. Two of the species in Vickery's list, *Euplectrus platyhypenae* Ashmead and *Frontina archippivora* (Williston) are already items of long standing in the fauna of Hawaii, and some of the others, for one reason or another, were not considered.

*THE HAWAIIAN PLANTERS' RECORD,* Vol. 48, No. 3, 1944 (Copyrighted).

Of the six species, whose introduction was attempted, two, *Apanteles marginiventris* (Cresson) and *Meteorus laphygmae* Viereck, are known to be established and this paper is intended mainly to familiarize the sugar planters with their habits and appearance. It is expected that in the course of time some or all of the other species will be recovered in the field, and as this occurs full accounts of their life histories will be published. For the present we offer only the facts of their introduction and some incidental notes which may prove of general interest.

### CHELONUS TEXANUS (Cresson)

This stout and vigorous braconid resembles our own *C. blackburni* Cameron and like it is a solitary endoparasite which oviposits in the eggs of the host and develops within the body of the larvae. When parasitizing *Laphygma frugiperda* it reaches full development in caterpillars of the fourth instar and causes them to cease feeding prematurely and to form a sort of pupal cell either in the soil, in trash, or, when reared in the laboratory, within tunnels which the caterpillars are likely to gnaw out in the process of feeding on young corn plants. Within this cell the parasite completes the destruction of the caterpillar and, leaving nothing but the outer skin undevoured, constructs a tough silken cocoon from which, in a matter of one or two weeks, it emerges transformed into an adult wasp.

Vickery found *Chelonus* parasitizing 33 per cent of all the small caterpillars collected in the vicinity of Brownsville and as high as 55 per cent of the collections from other places. From these figures he concludes that *Chelonus texanus* is the most important parasite of *L. frugiperda* in the Gulf Coast States; but although it is not specifically stated in Vickery's bulletin, it can be judged from the context that his figures were obtained mainly, if not exclusively, from collections made on corn. To the present writer, whose largest collections were always obtained in the grasses of fallow or uncultivated areas, Vickery's figures seem to exaggerate greatly the overall importance of *Chelonus*. While it was always true that this parasite seemed to be of predominant importance in young caterpillars collected on corn, there were several occasions when collections of from 500 to 1,000 caterpillars from grasses yielded no *Chelonus* at all or, perhaps, at most a dozen or so among hundreds of *Apanteles* and others. Nevertheless, the importance of *Chelonus* on corn in Texas and its presence in some quantity during all seasons of the year, sometimes when other parasites were nowhere to be found, are indicative of the potential value of the species to Hawaii.

It is known that *Chelonus texanus* is able to develop successfully on *Heliothis armigera* (Hubner), *Laphygma exigua* (Hbn.), one or more species of *Prodenia,* and *Ephestia sericaria* (Scott) the Mediterranean flour moth, in addition to *Laphygma frugiperda* and *Laphygma exempta,* so it would not have been difficult to rear enough of the parasites in the Texas laboratory for shipment to Hawaii if that had been necessary; but it was not. It proved quite simple, although somewhat laborious, to obtain enough parasites from caterpillars collected on young corn. Caterpillars of the proper stages were seldom more numerous than two or three per plant and almost always had to be cut out of the leaf spindle, which involved delicate and slow manipulating of both the plant and the insect, but once out of the spindle they were easy to handle. Carried to the laboratory in screen-top cans, they were placed over a layer of sand or soil in well-ventilated boxes and there permitted to remain undisturbed until the majority had stopped feeding and had dug into the sand. The sand was then carefully sifted and the caterpillars, most of them by now lying quiescent within cells moulded in the sand by the wriggling of their bodies, were transferred to small pill boxes. In the pill boxes, with the caterpillars carefully cushioned on loose cotton and not more crowded than four or five to a box, the larvae of *Chelonus* continued their development and eventually, when nothing but ragged pieces of the host remained, they constructed their cocoons, using the loose cotton and the sides of the box as bases of attachment for their spinning. In the same pill boxes, crowded into ordinary mailing tubes, the parasites reached Honolulu either in the cocoon stage or as adults, depending on the time that each consignment was in transit.

Apparently even under the most favorable conditions a large proportion of *Chelonus* larvae exhaust themselves while constructing their cocoons, and no practical manner was found to prevent this from happening while our material was en route. However, out of a total of 1,444 *Chelonus* shipped from Brownsville in seven consignments more than 900 arrived in Honolulu in good shape. Some of these were liberated directly in our fields. Counting them and the progeny of the others, there was made, between June 1942 and May 1943, a total of 19 liberations, which amountto 421 adult wasps, 300 small parasitized larvae of *Laphygma exempta,* and 250 egg masses of the same moth in which a majority of the eggs had been stung.

### NEOPRISTOMERUS APPALACHIANUS Viereck

This ichneumonid is apparently not of great importance in Texas. According to Vickery it was reared from *Laphygma exigua* and from one or more species of *Prodenia* but infested only 1.4 per cent of all the small caterpillars of *Laphygma frugiperda* collected in the course of Vickery's work. In our collections it was likewise scarce and no particular effort was made to reproduce the species in the laboratory or to introduce it into the Territory. Nevertheless, 65 specimens of *Neopristomerus* reached Honolulu at various times in vigorous condition and were liberated in *Laphygma*-infested fields on the islands of Kauai and Hawaii.

The life history of this species has not been worked out in detail but *Neopristomerus appalachianus* is known to be a solitary endoparasite. The present writer found it only on caterpillars of *Laphygma exigua* infesting corn and observed that these acted in a manner very similar to that of caterpillars parasitized by *Chelonus texanus, i.e.*, they stopped eating prematurely during the fourth or fifth instar and built a cell within which the parasite larva eventually finished the destruction of the host and spun a cocoon. The cocoons are made of thin, brown, paper-like material. Their upper surfaces are loosely woven and appear to be downy, and in shape they are cylindrical, about 9 mm. long and bluntly rounded at the ends. They are easily distinguished from cocoons of *Apanteles,* and with a little care it is also possible to distinguish the caterpillars parasitized by one species from those parasitized by the other. In practice, however, we avoided superfluous handling of our material by not separating the two species, so that *Neopristomerus* always arrived in Honolulu with larger consignments of *Chelonus*.

### PERISIEROLA sp.

The failure of Vickery and his collaborators to notice this active bethylid at work in the corn fields of Texas suggests that it may be a new arrival to the region. The small size, rapid movements and secretive habits of the species make it obvious that for every wasp observed many must pass unnoticed; but even so, at times they seemed quite common. The writer saw them frequently and believes that they may be a factor of considerable weight in the control of both *Laphygma frugiperda* and *Heliothis armigera.* They were particularly noticeable on still, hot days on young corn, but they were also found on full-grown corn and in short weeds and grasses which harbored small caterpillars. One cool and dewy morning, when a field of waist-high corn was visited just at sunrise, many males were found resting singly on the upper surface of the leaves; but whether this is the usual manner of their pernoctation and whether the females practice a similar habit was not ascertained.

The writer has seen *Perisierola* wasps attacking the second and third instars of *Laphygma frugiperda* and also one or more early but undetermined instars of *Heliothis armigera.* On corn they were frequently found pulling paralyzed caterpillars from the folds of the spindle and dragging them over the leaves of the plant, but they were never actually observed in the act of stinging or ovipositing. Apparently they will not oviposit in the field until the caterpillar is finally hidden in some nook which the wasp considers safe. Since no caterpillars bearing the eggs or larvae were ever found above ground, we may assume that *Perisierola* hides its victims in the soil or trash cover before ovipositing on them.

In the laboratory oviposition occurred readily on small *Laphygma* caterpillars collected with the wasps that were dragging them. On one occasion when a wasp and a third instar caterpillar, the latter completely flaccid, were placed together in a one-half-inch tube late one day and observed early the next, five eggs had been laid overnight. These had hatched 24 hours later and within 72 hours after hatching the resulting larvae had consumed all but the cuticle of the caterpillar and had spun small, brown cocoons of paper-like consistency from which adults emerged in eight days.

The eggs are less than a millimeter long; they glisten and are pearly gray in color. In shape they are rather elongately oval and more acutely rounded at one end than the other. They are laid exteriorly on the dorsum and sides of the abdominal segments, always parallel to the longitudinal axis of the caterpillar but oriented either towards the head or the caudal end of it and apparently without discrimination as to the segment on which they are placed.

No attempt was made to rear *Perisierola* in quantity or to introduce the species into the Territory.

### METEORUS LAPHYGMAE Viereck

*Meteorus laphygmae* is one of two species among our Texan introductions which are known to be established in the Territory. It has been recovered in two instances from Field 13 of the Oahu Sugar Company, Ltd. The first time, January 20, 1944, it was reared from a caterpillar of the beet armyworm (*Laphygma exigua*), and the second, January 26, 1944, from a caterpillar of the corn-ear worm (*Heliothis armigera*). Later, April 1944, *Meteorus* was also found well-established on the island of Hawaii. At that time, James T. Nagasako of Hawaiian Agricultural Company, Pahala, submitted for identification numerous adults and cocoons which he had collected in two fields of that plantation, in one of which liberations had been made on December 3, 1942.

Evidence that both *Laphygma exigua* and *Heliothis armigera* are attacked by *Meteorus* is of special significance, not only because it augurs a desirable reduction in the population of the latter pest as well as the former but because it shows the ability of the parasite to spread and to perpetuate itself during the long intervals of scarcity which characterize the history of the grass armyworm in Hawaii.

Vickery found that in Texas, *Meteorus* was second in importance only to *Chelonus texanus* among the parasites of *Laphygma frugiperda*. In the present writer's experience it was found less often on corn than *Chelonus*, *Apanteles*, or *Rogas*, but more often than any of the others on grasses. Search of Bermuda grass lawns in the city of Brownsville seldom failed to show indications of its presence, and on several occasions isolated infestations of *Laphygma* on such lawns were apparently wiped out by this parasite alone. However, the largest collections were made on forage grasses, often waist-high and over.

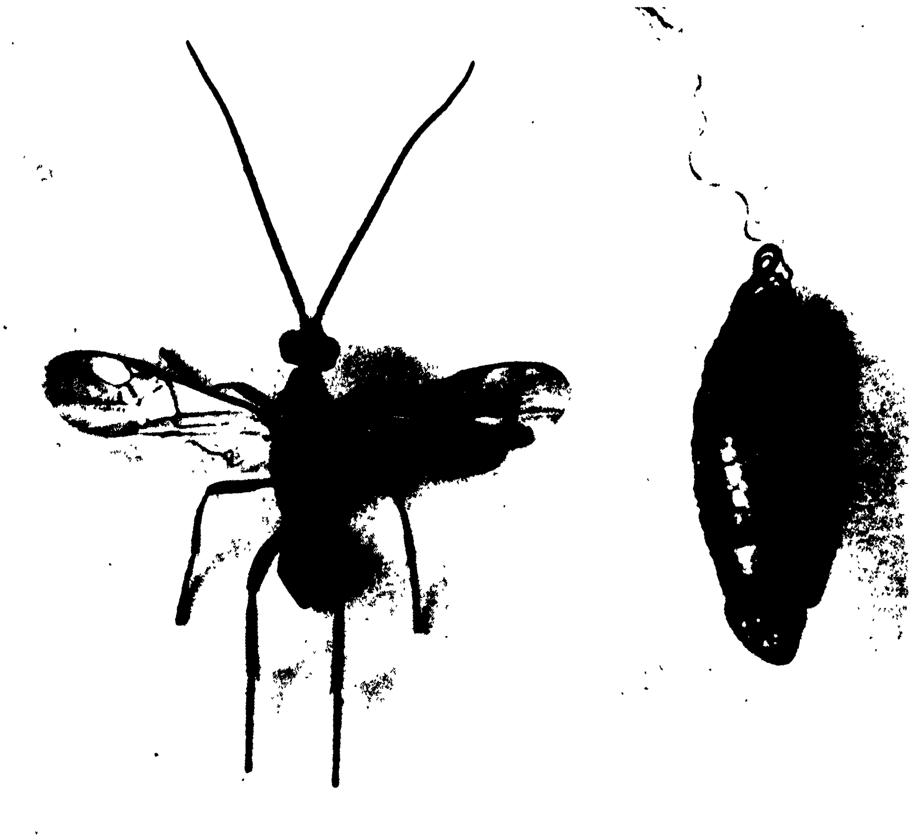

Fig. 1. Adult female wasp and cocoon of *Meteorus laphygmae* Viereck. Note the long, thin thread on which the cocoon swings from the point of attachment.

The finer details of the life history of this parasite are not known but Vickery's researches have provided an outline of the facts. According to that author, *Meteorus* is far from being exclusive in its choice of host and has been reared in Texas from at least eleven species of caterpillars, of which some, *Heliothis armigera* (Hub.), *Cirphis unipuncta* (Haw.), and *Laphygma exigua* (Hbn.), are common in Hawaii and others have near relatives among us. When attacking *Laphygma* *frugiperda* the small and active wasp will oviposit readily on caterpillars of the first and second instars but it refuses, in the laboratory at least, to oviposit in those of the third and later instars. How long after oviposition the parasitic larva reaches full development and is ready to leave the host apparently depends only to a small extent on the instar of oviposition, but the time is likely to vary widely according to prevailing temperatures. In warm weather (83° F.) it may be as short as seven days, but in cool weather (69–70° F.) it may be as much as 14 days, and at lower temperatures it would probably be much longer. Whatever the duration of this interval, the parasitic larva always leaves the caterpillar during the fifth instar of the caterpillar's life and the caterpillar does not die immediately. In spite of the perforation in its body-wall, through which the parasite makes its exit, it may live several days. The parasitic larva, meanwhile, proceeds to spin a cocoon and to transform within it into a pupa and later into the fully developed wasp. Still, according to Vickery, the first of these transformations takes place soon after completion of the cocoon and the second shortly before emergence of the wasp, so that for practical purposes the time from the spinning of the cocoon to the emergence of the wasp can be considered equivalent to the duration of the pupal stage. This was observed by Vickery to vary between five days at a mean temperature of 83° F. to 17 or 19 days at the unspecified but presumably much colder temperatures of January.

The potential rate of reproduction of the species is indicated by Vickery in his statement that *Meteorus* can probably complete 18 generations during the year, and in his observation of one female which in the course of nine days successfully parasitized 83 caterpillars.

While the adults of *Meteorus* are small and inconspicuous wasps, their cocoons are curious and very characteristic objects which despite their small size are certain to attract attention. Of unusually tough texture, they are about four mm. long, spindle shaped, tapering from the middle to both ends, and a polished brown in color, their special character being due to the manner of their attachment to the host plant. Instead of resting directly on a leaf or stem they hang from one end on a thin, tough thread two or three inches long and swing wildly with the lightest breeze. Undoubtedly such an attachment is of some use as a protection against predatorial enemies of the species; but in a stiff Texas "norther" one is always led to wonder how many of the delicate *Meteorus* larvae might have gladly exchanged a measure of safety for a little more comfort. Particularly in view of the fact that at least one of the hyper-parasites of the species, a small, thick-legged wasp of the genus *Spilochalcis,* is often found clinging stoutly to the cocoons of the host and ovipositing therein in obviously calm disregard of the wild gyrations of its perch.

As was the case with our other species, it was not necessary to breed this parasite in the laboratory. Cocoons were collected in the field and sent to Hawaii as such or kept in Brownsville until the adults had emerged. The shipping cages used were of a type employed often before in similar work,* and the only innovation in our manner of using them consisted in the frequent inclusion of cocoons with the adults. For this purpose cocoons were crowded into a small pill box securely nailed to the inside of the cage and perforated with a number of small holes through which

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*** Petersen, Alvah, 1934. A manual of entomological equipment and methods. Edward Bros., Ann Arbor, Mich.**

wasps emerging in transit could crawl out to join the other wasps in the cage, wherein food and moisture were provided by means of raisins and a small vial with a wick. In our first shipment some mortality of the adults occurred because the cocoons in the pill boxes were too crowded and emerging wasps were not able to push their way through them; but in later shipments the cocoons were divided into two pill boxes and the factor of overcrowding was eliminated.

From June to November of 1942, seven shipments of *Meteorus* were made, totalling some 3,200. Many of the adults were dead or too weak to be of use upon arrival in Honolulu. Nevertheless, some two-thirds of all the material shipped reached Honolulu in good shape and most of it was liberated directly in the field. Counting these liberations and some progeny reared in the Honolulu laboratory about 3,900 wasps were distributed in various fields of Oahu, Maui, Kauai, and Hawaii between June 1942 and June 1943.

### ROGAS LAPHYGMA Viereck

This is another solitary endoparasite of the family Braconidae. Vickery and the writer reared it exclusively from *Laphygma frugiperda* in Texas, but in our Honolulu laboratory it also parasitized *Laphygma exempta* without hesitation. It oviposits in caterpillars of the first instar and attains full larval development in those of the fourth. Then, instead of crawling away from the remains of its victim as other parasites do, it spins a thin cocoon within the empty skin of the host and proceeds to pupate therein. The skin containing the parasite shrinks somewhat in size, acquires a dry, paper-like consistency and becomes entirely brown in color, and can be easily mistaken for a real cocoon of some other species. It is securely glued along its ventral surface to whatever object the caterpillar happens to die upon. On corn plants it is usually found on the leaves.

Vickery ranked *Rogas* eighth in importance among the parasites of *Laphygma frugiperda* and stated that it was found infesting only from one-half to two per cent of all the small caterpillars collected over a period of five years. To the present writer it seems that *Rogas* must attain at times a much greater incidence than this. The nature of our work impeded the keeping of quantitative records but, even without them, it was obvious that the cocoons of *Rogas* were present at times in corn plantings where no other parasites were to be found, or where they were very scarce. In one such field of some two acres it proved possible on one occasion to collect 200 cocoons in three days.

These cocoons plus 17 more constituted the only substantial shipment of *Rogas* that was made to Hawaii and, unfortunately, it was not quite successful, yielding only 47 vigorous adults. With this relatively small number of wasps to begin with and in the face of heavy mortality among their progeny no determined effort was made to establish the species. Only two small liberations were made—ten adults at Olaa Sugar Company on June 24, 1942, and 45 adults at Pepeekeo Sugar Company on August 11 of the same year—on the chance that they might prove unexpectedly successful.

### APANTELES MARGINIVENTRIS (Cresson)

This is another small and inconspicuous braconid, more likely to be noticed in the field as a cocoon than in the adult stage. Its life history has not been thoroughly studied, but Viereck reared it in Brownsville from one or more species of *Prodenia*, one species of *Autographa*, *Plathypena scabra* Fab., *Cirphis unipuncta* (Haw.), *Heliothis armigera* (Hubner), *Laphygma exigua* Hubner, and *Laphygma frugiperda* (S. and A.), and he observed that in the laboratory the wasps oviposit in the first instar of *Laphygma frugiperda* soon after the caterpillars hatch from the eggs and before they disperse from the immediate vicinity of their hatching. Oviposition takes place through a single flash-like stab of the ovipositor and it does not seem to discommode the victims in any way. Although they invariably fail to attain the full size of unparasitized caterpillars they continue to feed and to behave normally until their fourth instar. At this stage the larva of *Apanteles* has reached full growth and gnaws its way out of the caterpillar through a hole in the body wall which is often a remarkably large and angry wound but does not result in the immediate death of the caterpillar. The caterpillar crawls away to live several hours longer, and meanwhile the *Apanteles* larva proceeds to spin the cocoon in which it is to transform into a wasp.

The cocoon of *Apanteles*, as shown in the accompanying illustrations, is creamy white, sometimes tending to yellow, and is about three mm. in length by about one mm. in thickness in the middle. Its shape is that of a cylinder with both ends bluntly rounded, and on close inspection its walls are seen to be smooth and glossy only within, being downy and irregular outside because the outer layers of thread are not tightly woven. On corn and grasses the orientation of the cocoon is almost invariably parallel to the long axis of the leaf and, at least on grasses, the place of attachment is usually the median groove of the leaf. The attachment is secure and difficult to break without injuring the cocoon and is attained by means of threads whose

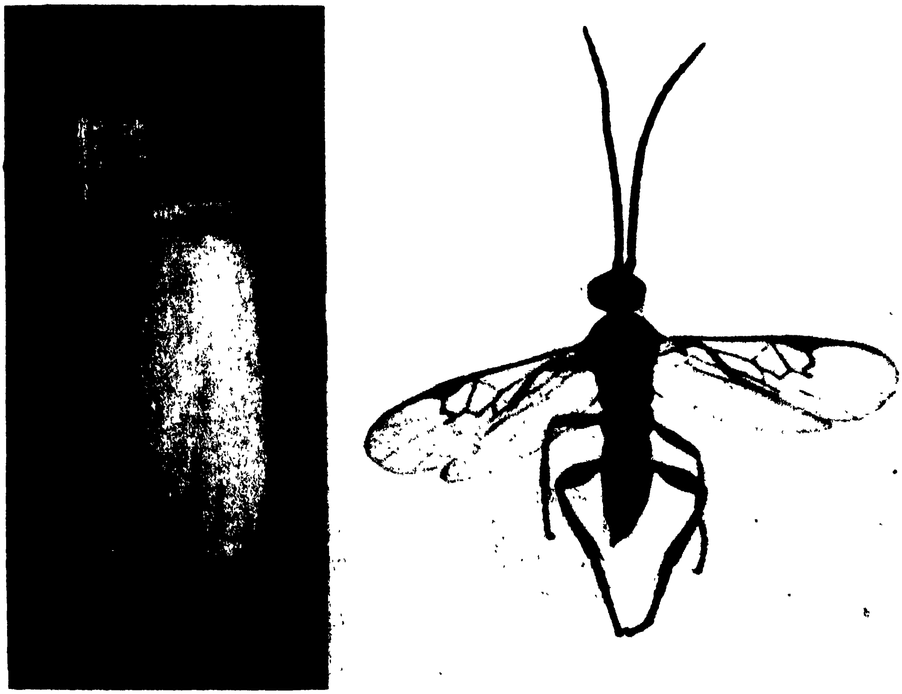

**Fig. 2.** **Adult female wasp and cocoon of *Apanteles marginiventris* (Cresson); the latter showing the trap door-like cap over the opening through which the adult wasp has emerged.**

ends are firmly glued to the substratum. Empty cocoons are sometimes not immediately distinguished from others because of the delicate manner in which the wasps make their exit from them. Instead of indiscriminately gnawing a ragged hole anywhere on the cocoon as some other parasites do, *Apanteles* makes a smooth circular cut near one end and issues by lifting the end of the cocoon like a conical trap door which after emergence of the wasp is likely to fall back to its original position and to hide the parasite's escape.

In Brownsville the present writer found that the cocoons of *Apanteles* are much more likely to occur on the exposed leaf sheaths of the host plant than within the protection of the spindle or near the stalk of the plant or near the ground, where caterpillars are as likely to be collected during dense infestations as anywhere else. Why this happens is not known, but in explanation two alternative possibilities may be postulated which may some day provide the basis for an interesting study. One of these is that some environmental factor or factors, possibly light, warmth, host-movement, or host-position, determines the precise time at which the full-grown larva of *Apanteles* leaves the host. The other, that the emergence of the parasite is not restricted within sharp limits of time and that some factor exists which causes the caterpillar to remain on the exposed leaves of the host-plant until the parasite has emerged. The question, of course, seems presently only of academic interest; but, as in the case of all such questions, it is not possible to foresee when it might become of economic significance as well.

The duration of the larval and pupal stages combined, that is, the time between oviposition and emergence of the adult *Apanteles* from its cocoon, was found by Vickery to vary considerably from one season of the year to another. During the warm summers of Brownsville it was only about ten days but during the cold winter months it lengthened to as much as 27 days. With us in Hawaii the average must lie closer to Brownsville's minimum than to its maximum, but it remains yet to be accurately determined, as do other fine points of the parasite's life history.

The introduction of *Apanteles* into Hawaii took place entirely during the last half of 1942. Employing the same methods and equipment with this species as with *Meteorus laphygmae*, three shipments of cocoons were made, the first on August 12, the second on November 12, and the third on November 16, and from this material a total of 664 vigorous adults was obtained in Honolulu. Some of these were mated in the laboratory and released at once, and with the rest a program of laboratory breeding was undertaken which between November 1942 and June 11, 1943, the date of the last liberation, produced 4,277 adults distributed to the various islands as follows: to Hawaii, fifteen consignments totalling 2,126 adults; to Maui, eight consignments totalling 1,410 adults; to Oahu, two consignments totalling 230 adults; to Kauai, two consignments totalling 511 adults.

Vickery wrote that less than two per cent of his collections of five years in the Gulf District of Texas were parasitized by *Apanteles marginiventris;* but, as Vickery himself believed, this figure is probably an under valuation of the importance of the species. Although in the experience of the present writer *Apanteles* was not as easy to find on corn as *Chelonus* or *Meteorus* or even *Rogas laphygmae*, it was often common and at times noticeably abundant on grasses, appearing on more than one occasion as the main, if not exclusive factor in the elimination of small, dense populations of *Laphygma frugiperda.*

That *Apanteles* will also become an important factor in the control of armyworms and cutworms in Hawaii seems certain. The adaptability of the species to our conditions is shown by its quick establishment, and its value in our scheme of biological control is assured by its habits. Parasitizing exclusively the early instars of its various hosts, it will provide just the link that has been missing hitherto in our series of armyworm and cutworm parasites. With its addition to our fauna we now have one or more parasites working on each stage in the development of the hosts, from the egg stage to the mature larvae.

While so far most recoveries have been of the cocoon stage in grasses and weeds, indicating that *Laphygma exempta* and *L. exigua* will probably be the usual host of *Apanteles* in the Territory, on at least one occasion the parasite was reared from a field-collected caterpillar of *Heliothis armigera*. This is gratifying to record, for, since both *Apanteles marginiventris* and *Meteorus laphygmae* are known to parasitize *Heliothis* in the mainland United States, the establishment of both parasites in our Territory may well result in considerable reduction of the damage which *Heliothis* does to our increasingly important corn crop.

It is an interesting reflection upon the high biotic potential of the species, as well as upon the unpredictability of biological control in general, that *Apanteles* was first recovered, during February of 1943, on the grounds of the Experiment Station at Makiki, where the population of caterpillars had been judged too thin to warrant a formal liberation of any parasites and where *Apanteles* must have obtained a toe hold through the unsuspected efficiency of some few specimens which had been discarded as too old and spent for further laboratory breeding. The second recovery was made shortly after the first in the Pathology Plot on Alexander Street, where no liberations whatever had been made and where *Apanteles* can have arrived only by overcoming the hazards interposed by several blocks of densely populated urban property. Since then, recoveries have been made from other localities on Oahu (Waialua and Oahu Plantations) and from the islands of Kauai, Hawaii, and Molokai. On Kauai the first cocoon was found by C. E. Pemberton at Wailua Orchard on September 23, 1943. On Hawaii many cocoons and adults were found in April 1944 by Mr. Nagasako, Hawaiian Agricultural Company, Pahala, in the same fields and at the same time that *Meteorus* was first seen. The most remarkable record of all, however, is that of the recovery of *Apanteles* on the island of Molokai. It was first found there by Mr. Pemberton on April 21, 1944, and, since no liberations of the parasite were ever made on that island, it is presumed to have found its way there as an accidental stowaway on a ship or plane or as flotsam on air currents.

# Soil and Plant Material Analyses by Rapid Chemical Methods—IV

## The Clements' Method of Crop Control Adapted to RCM*

(Revised to RCM Procedure in a Laboratory Comparison Study by the Chemistry Department, Experiment Station, H.S.P.A., and Adjusted to Embrace Suggestions Based Upon a Critical Review by the Originator of the Method and His Staff.)

*A summary of the Clements' method of crop control appeared in the* Record *in the fourth quarter issue 1943. The present contribution consists of an adaptation of the analytical control determinations from standard laboratory practice to conventional RCM procedures. The revision and recasting of the analytical methods to RCM were made upon requests of plantation staffs interested in the study, and with the permission of Dr. H. F. Clements. A distinct contribution by the Chemistry staff of this Experiment Station embraces the tables appearing in the text of the RCM procedures and by which the analyst is relieved of the responsibility of making chemical calculations.*

The principles underlying this method of crop control were discussed and explained in an article by Dr. H. F. Clements.† Dr. Clements has in preparation additional subject matter and data which he will undoubtedly present in future published articles. Several plantations in the Territory are employing the method as outlined by the author and are making the necessary laboratory determinations on a scale comparable to that which would be carried out in any first-class, well-established chemical laboratory in the hands of university-trained chemists.

A number of plantation managers and their agriculturists have noted that the laboratory procedures used in the control method are somewhat technical and difficult to handle, and consequently are beyond the reach of adoption by the plantation RCM laboratory staff. Therefore, upon repeated requests from interested managers and agriculturists, and with the permission and cooperation of the author, the staff‡ of the Chemistry department of this Experiment Station undertook the modifications and recasting of the procedures in simplified and chronological order on the basis of the laboratory technic which is common to RCM analyses. It was necessary to deviate somewhat from the original technic of analysis and to employ

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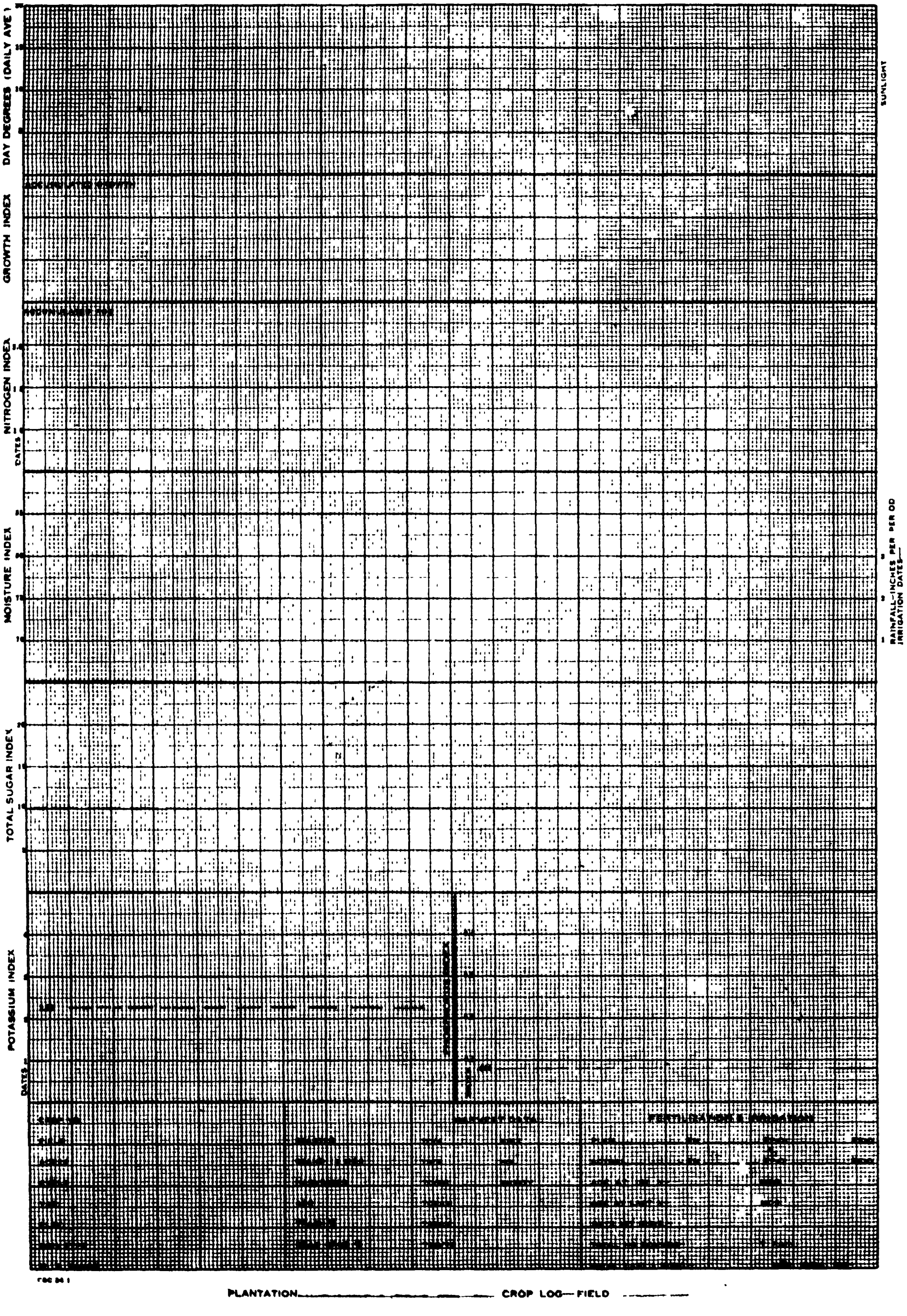
* The term "RCM" implies rapid chemical methods of soil and plant analyses. This abbreviation has been in use for about 15 years to designate a system of analyses developed at this Experiment Station and used by plantations and Experiment Stations throughout the Territory, and in a number of agricultural laboratories in South America, Europe, Africa, and Asia.

† The Primary Index, Its Meaning and Application to Crop Management With Special Reference to Sugar Cane. The Hawaiian Planters' Record, 47: 257–297, 1943.

‡ Several members of the Chemistry department, Experiment Station, H.S.P.A., contributed to the revision and recasting of the Clements' crop control analytical procedures. Those participating were M. Doi, Geo. K. Uyehara, F. Ray Van Brocklin, Richard Boyen, P. L. Gow and Francis E. Hance.

Fig. 1. The Clements' crop-log form.



standardized reagents and equipment prepared for the RCM analyst in a chemistry laboratory. However, the principles of analytical procedure as described by Dr. Clements have not been materially altered. By adhering to the system adopted in previously developed RCM* procedures, the analyst using this recast of Clements' crop control is relieved of the necessity of making chemical calculations which might give him difficulty or result in erroneous findings. Instead, in all cases, his final analytical data are referred to convenient tables (attached hereto) where his end result may be found tabulated for him and from which the index he seeks may be noted and transferred to the crop-log sheet. This act terminates the duties of the RCM analyst. From this point forward the agriculturist takes over, for it is at this stage of the study that the "control" becomes operative.

The Clements' method of crop control is unique in that it employs periodic determinations made by the standard Experiment Station, H.S.P.A., leaf-punch nitrogen analysis of cane blade specimens as a running index of this nutrient. In addition to this, it includes a study made progressively with the growth of the crop upon the moisture, sugars, potassium and phosphorus relationships as they may exist from period to period and as they may vary in the leaf-sheath portion of the sugar cane plant.

The control is regulated by information recorded on a printed crop-log form prepared by Dr. Clements (Fig. 1). It constitutes essentially a running record of the growing crop. It carries determinations of nutrient values made from time to time on the plant, showing deficiencies or excesses of the principal fertilizer constituents. These data, together with other recorded observations, constitute the basis on which a diagnosis is made of the condition of the crop. Nutrient constituents may be applied to the current crop in an endeavor to correct deficiencies which the systematic log ostensibly has brought to light. The log records harvesting, fertilization and irrigation data, and nutrient indices, the latter falling within certain limits of concentration and which, by varying from predetermined values of sufficiency, supply data to the agriculturist upon which he may take action. The log sets forth, progressively under appropriate date lines, the following indices: potassium, phosphorus, total sugars, moisture and nitrogen. The log also embraces recordings of growth as an index and sets forth the daily average day-degrees of temperatures. Rainfall is noted on the log, together with irrigation data. Other field data are included which bear specifically upon the crop.

The RCM version of the control analyses deals only with laboratory procedures which bring the method within the reach of any RCM laboratory now operating. Apparatus, reagents, accessories and equipment (with few exceptions) are prepared and standardized in the RCM division of the Chemistry department and are being made available to plantation RCM staffs who wish to include the Clements' method of crop control in their field studies.

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* Hance, Francis E., 1936. Soil and plant material analyses by rapid chemical methods. The Hawaiian Planters' Record, 40: 189–299. (Agric. and Chem. Series Bulletin No. 50.)

——————, 1937. Soil and plant material analyses by rapid chemical methods—II. The Hawaiian Planters' Record, 41: 135–186. (Agric. and Chem. Series Bulletin No. 51.)

——————, 1941. Soil and plant material analyses by rapid chemical methods—III. The Hawaiian Planters' Record, 45: 265–296. (Agric. and Chem. Series Bulletin No. 53.)

The original text of the author has been inserted at various points (under quotes) to clarify certain phases of the procedure. Several revisions have been made from the RCM recasting of the method as based upon constructive criticism and suggestions by the author of the method and his staff. We offer the regular RCM checking service which, as in the case of other RCM studies, is made available to the plantations without charge.

The Experiment Station recommends that, should the plantations decide to include the Clements' method of crop control in their research curriculum, the RCM operator who may be selected for the work be given a 10- to 20-day course of instruction in the Chemistry department of this Experiment Station prior to his undertaking the study on the plantation.

## FACTORS GOVERNING SELECTION OF CANE STALKS FOR SAMPLING

In using Clements' method of crop control it is necessary to recognize certain comparatively simple facts, especially with reference to sampling.

*First:* The final crop of sugar cane is made up of those sticks which have survived the competition of the previous period of growth. Thus at about three months of age, a cane crop may average anywhere from six to as many as twelve young shoots per running foot of line. These include some strong and some weak shoots. Usually, by the time the crop is a year old, the weaker shoots are dead and dried up. These dead shoots either decay, or what remains of them is destroyed by the slash fire at harvest. Only the stronger shoots succeed in contributing to the harvest. It is, therefore, apparent that samples selected should represent the average of the strong tops, that is, those which are likely to be there at harvest.

*Second:* Suckers which develop after the crop is from 10 to 14 months old usually contribute a small part of the final crop. Where such is the case it is obvious that suckers should not be included in the samples. Actually the sucker growth differs considerably from the main crop, not only in age, but in succulence and hence cannot be mixed into the samples. However, where the late sucker growth is considerable, so that an estimate would place that portion of the crop at about 50 per cent of the total, it is clear that two crops are growing in the field and separate samples must be taken from the sucker crop. At best, we can only hope to bring the two crops to harvest with least damage to either one. It is therefore apparent that one does not sample a field according to mathematical chance. He *selects* his plants as representing the major stand of plants which will be there at harvest.

*Third:* The size of the area included in a single sample will be determined by the nature of the area. If the field is uniform in elevation, exposure, slope and moisture, it can be sampled as a single area, no matter how large it is. If, on the other hand, the area is small but extremely variable in slope and moisture, etc., it will be necessary to have two or more sampling areas. Thus a field with sharp gullies and ridges can best be handled by sampling the ridges as one area and the gullies as another. Or, if a field is a narrow strip on a steep slope, so that considerable variation in elevation obtains, it may be necessary to divide the field into two or more areas. Again, one must consider the percentage factor in laying out sampling areas. If a field is largely one kind of area, with minor parts of the field at variance, he may decide to ignore the spots or smaller areas. Or he may sample these separately.

It is clear, therefore, that the size of the field area sampled has to be decided for each particular field with special attention given to variations in slope, elevation, exposure, drainage and moisture. When this method is to be applied to a new field, it is best to break the field into several sampling areas. After the samples are analyzed, the smaller areas can be combined into larger areas as determined by the uniformity of the analyses.

*Fourth:* A little experience on the part of the sampler is needed. At first he should be required to select several samples from small areas. In selecting a sample, the plants making up the important stand are taken. These should be selected well away from borders and main irrigation ditches and should be taken from several representative spots in the field.

*Fifth:* Since in this method we are interested in obtaining a picture of the general physiological status of the crop, we need to avoid as much as possible the influences of the day on which the samples are taken. It is therefore necessary to collect the samples early in the morning—preferably just after sunup and to limit sample gathering to the first two or three hours of the day.

*Sixth:* Samples are collected at intervals of five weeks, beginning as soon as the small plants have the necessary leaves and sheaths.

## PREPARATION AND STORAGE OF SAMPLE

The sample is made up of tops of five representative plants selected as described above. Having selected a particular plant, find the spindle leaf—the one sticking out of the top of the plant—and call it No. 1. Count the leaves downward in order through No. 6. Cut the stalk somewhere below the attachment of this leaf without removing the older leaves. (If these leaves are left on, the same stalk remaining in the field will develop lalas and will not be lost.) One sample consists of five such tops removed from various parts of the fields. If many samples are to be gathered in one morning, it is best to roll each five tops into a bundle and to label properly. The label may be written with a No. 2 (soft) pencil directly on the exposed sheath of each top. KEEP THE SAMPLE CLEAN AT ALL TIMES.

The sample or samples are taken to the laboratory and leaves Nos. 3, 4, 5 and 6 are carefully removed from the stalk. This is best accomplished by using a strong sharp knife. The stalk is cut across exactly at the point of contact of the sheath to the stem. After the cut, the sheath is rolled off. Then the next cut is made across the base of the next sheath, etc. It is important that the cut be clean so that no cane tissue is carried by the sheath. With practice this operation takes very little time. Since each top will give four leaves, each sample will give twenty such leaves. The remaining material is discarded. Each of the twenty leaves is then separated at the brown mark into sheath and blade.

After determining the moisture and green weight (procedure outlined below) the dried material is ground to a near powder and may be stored until analysis. If several weeks pass before analysis, the sample should be redried before weighing.

## DETERMINATION OF MOISTURE AND GREEN WEIGHT

(Adapted from Dr. Clements' original text)

*Equipment:*

1 balance, capacity 1,500 grams
1 set balance weights, 1 mg. to 1,000 grams
1 butcher knife or cutter (paper-cutter type)
1 drier*
1 grinding mill

*Procedure:*

1. Weigh each bundle (20 sheaths each) on an accurate balance. Record weight. This is GREEN WEIGHT of the sample.

2. After weighing (using a strong, sharp knife of the paper-cutter type), cut sheaths into half-inch lengths.

3. Place chopped sample on a screen tray in the drier (equipped with a strong blast and enough heat to maintain approximately 90° C.) for about three hours.

4. Test completion of drying by reweighing the sample and returning it to drier for another hour.

*Note:* As the operator gains experience, he can take pieces of the chopped sheaths and test their dryness by the way they snap when bent.

5. Weigh dried sample on accurate balance and record weight. This is DRY WEIGHT OF SAMPLE.

6. Subtract DRY WEIGHT from GREEN WEIGHT. The result is MOISTURE CONTENT.

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* Blueprints of an efficient drier are now available from the Engineering Committee, Experiment Station, H.S.P.A.

7. The MOISTURE CONTENT, when multiplied by 100 and divided by GREEN WEIGHT of sample gives PER CENT MOISTURE or MOISTURE INDEX.

## THE NITROGEN INDEX BY RCM

The twenty leaf blades referred to above under "Preparation and Storage of Sample" are the tissues used in this analysis. Three leaf punches are taken from each leaf in a region located about half way along the blade and one-half the distance between the midrib and the outer edge of the leaf. Details of the method to be used in determining the nitrogen index have previously been published.* Follow the analytical procedure in the leaf-punch method, but employ the Clements' technic for collecting the sample.

## PRIMARY INDEX (TOTAL SUGARS) BY RCM

*Reagents:*†

5 gallons distilled water
½ pint reagent 45, S
1 gallon reagent 46, S
1 gallon reagent 47, S
1 gallon reagent 48, S
½ pint reagent 49, S
1 gallon reagent 50, S

*Equipment:*

1 student-type analytical balance, sensitive to 0.1 mg.
1 aluminum balance scoop, 10-ml., with counterpoise
10 Erlenmeyer Pyrex flasks, narrow mouth, 500 ml.
1 hot-water bath
10 rubber stoppers No. 6 fitted with 15″-length of 13-mm. glass tubing, for 500-ml. Erlenmeyer flasks
1 wooden clamp for removing flasks from source of heat
10 glass funnels, 90-mm. diameter
1 pkg. Munktell No. 3, 15-cm. filter paper
10 volumetric Pyrex glass flasks, 500 ml.
1 five-gallon bottle fitted with stopper and siphon for distilled water
10 feet ¼ x 1/16″ rubber tubing with glass nipple and pinchcock for siphon
10 Pyrex beakers, 600 ml.
10 volumetric Pyrex flasks, 250 ml.
1 graduated cylinder, 250 ml., for transferring filtrate to volumetric flask
1 electric hot plate, 3-heat
1 Mohr pipette, 10 ml., for reagent 50, S
1 dropping bottle, pipette stopper, 60 ml., for reagent 45, S
1 burette, 50 ml., for reagent 46, S
1 burette, 50 ml., for reagent 47, S
10 Erlenmeyer Pyrex flasks, narrow mouth, 300 ml.
1 Mohr pipette, 5 ml., for reagent 48, S
1 burette, 50 ml., for inverted extract

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* Hance, Francis E., 1941. Soil and plant material analyses by rapid chemical methods—III. The Hawaiian Planters' Record, 45: 265–296. (Agric. and Chem. Series Bulletin No. 53.)

† Complete details regarding the preparation of reagents are included elsewhere in this article.

2 iron support stands, 6 x 9″ base, with rods } for 50-ml. burettes
2 Lincoln burette clamps }
1 dropping bottle, pipette stopper, 60 ml., for reagent 49, S
1 thermometer, 0–100° C.

*Procedure:*

1. Weigh out exactly five grams of the ground and dried sheath material and place in a 500-ml. Erlenmeyer flask.

2. Add 300 ml. of distilled water and place flask on electric hot plate* for three hours at near boiling. Stopper flask and fit with a 15″ length of fairly large glass tubing in order to materially reduce losses from evaporation.

3. Using a wooden clamp, remove flask from hot plate and filter through Munktell No. 3, 15-cm. filter paper (using 90-mm. funnel) into a 500-ml. volumetric flask.

4. Wash residue remaining on filter five times with 20 to 30 ml. of distilled water each time. Direct stream of distilled water entirely around the upper edges of the filter paper about ¼-inch from top. Allow distilled water to drain thoroughly after each washing.

5. Discard residue.

6. Make filtrate up to volume (500 ml.) with distilled water and mix thoroughly by pouring all of the filtrate into a clean, 600-ml. beaker.

*Note:* This filtrate contains sucrose, reducing sugars and potash.

7. Using a 250-ml. graduated cylinder, transfer accurately 200 ml. of the filtrate to a 250-ml. volumetric flask and heat on hot plate to 65–70° C.

8. Before removing flask from hot plate, from a 10-ml. Mohr pipette immediately add 10 ml. of reagent 50, S to contents of flask.

9. Remove flask from heat with wooden clamp; let it stand for one hour.

10. Cool to room temperature and then add five drops of reagent 45, S from dropping bottle.

11. Carefully neutralize with reagent 46, S from a 50-ml. burette to faint pink color.

12. Make up to mark (250 ml.) with distilled water and mix thoroughly.

*Note:* This represents the INVERTED EXTRACT.

13. From an accurate 50-ml. burette measure exactly 5 ml. of reagent 47, S into a 300-ml. Erlenmeyer flask.

14. Using a 5-ml. Mohr pipette, add 5 ml. of reagent 48, S.

15. From another accurate 50-ml. burette, add 25 to 30 ml. of inverted extract (from step No. 12).

*Note:* Add more of the inverted extract if the percentage of sugars is known to be low.

16. Place flask on the type "H" electric heater. (Reverse heater refractory so that its bottom or flat surface faces upward.) Add three to four perforated glass beads to contents of flask. Heat contents to boiling and continue to boil for exactly two minutes.

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*** In regular, established laboratories the following procedure may be followed in Step No. 2: Add 300 ml. of distilled water and place flask in a hot-water bath (near boiling). Heat for three hours. (*Note:* Blue prints for a suitable water bath are available at the office of the Engineering Committee, Expt. Sta., H.S.P.A.)**

*Note:* If the solution in the flask is still quite blue after it starts to boil, add *carefully* more of the inverted extract from the burette until the bluish tint disappears. (Burette reading will be needed later.)

17. After boiling for two minutes, and while flask remains on heater, add from dropping bottle five drops of reagent 49, S. Arrange burette containing inverted extract so that titration with inverted extract may be made without removing flask from heater. Add more inverted extract, a little at a time, until blue color occasioned by addition of reagent 49, S completely disappears. (Do not remove flask from heater until titration has been completed. Titration should be completed within one minute after boiling.)

18. Remove flask from heater and record exact burette reading.

*Note:* If no color develops in solution in Erlenmeyer flask upon addition of reagent 49, S, too much inverted extract has been added. If more than 89.0 ml. of inverted extract were required to decolorize 5 ml. of reagent 47, S make another extraction using ten grams of ground sheath material and divide indicated percentage by two.

19. Read percentage of invert sugar in the dried sample directly from table.

*Example:*

5 grams ground sheath material extracted.

48 ml. = titration with inverted extract.

From table: 48 ml. = 13.62 per cent total sugars in original dry material, expressed as invert sugar.

TABLE OF PER CENT INVERT SUGAR IN FIVE GRAMS OF ORIGINAL DRY SAMPLE

| ml. inverted extract used | Per cent invert sugar | ml. inverted extract used | Per cent invert sugar | ml. inverted extract used | Per cent invert sugar |
|---|---|---|---|---|---|
| 20 | 31.87 | 43 | 15.12 | 66 | 10.25 |
| 21 | 30.37 | 44 | 14.87 | 67 | 10.12 |
| 22 | 29.00 | 45 | 14.50 | 68 | 10.00 |
| 23 | 27.75 | 46 | 14.25 | 69 | 9.90 |
| 24 | 26.62 | 47 | 13.87 | 70 | 9.80 |
| 25 | 25.62 | 48 | 13.62 | 71 | 9.70 |
| 26 | 24.62 | 49 | 13.37 | 72 | 9.60 |
| 27 | 23.75 | 50 | 13.12 | 73 | 9.50 |
| 28 | 23.00 | 51 | 12.87 | 74 | 9.40 |
| 29 | 22.25 | 52 | 12.62 | 75 | 9.30 |
| 30 | 21.37 | 53 | 12.37 | 76 | 9.20 |
| 31 | 20.75 | 54 | 12.12 | 77 | 9.10 |
| 32 | 20.12 | 55 | 11.87 | 78 | 9.00 |
| 33 | 19.62 | 56 | 11.75 | 79 | 8.90 |
| 34 | 19.00 | 57 | 11.62 | 80 | 8.80 |
| 35 | 18.50 | 58 | 11.37 | 81 | 8.70 |
| 36 | 18.00 | 59 | 11.25 | 82 | 8.60 |
| 37 | 17.50 | 60 | 11.12 | 83 | 8.50 |
| 38 | 17.12 | 61 | 10.87 | 84 | 8.40 |
| 39 | 16.62 | 62 | 10.75 | 85 | 8.30 |
| 40 | 16.25 | 63 | 10.62 | 86 | 8.20 |
| 41 | 15.87 | 64 | 10.50 | 87 | 8.10 |
| 42 | 15.50 | 65 | 10.37 | 88 | 8.00 |
| | | | | 89 | 7.90 |

**Note:** If the titration goes beyond the limit of this table, it will be necessary to repeat the extraction using ten grams of the ground sheath material. When a ten-gram sample is used, indicated percentage (from table) should be divided by two.

## The Potassium Index by RCM*

*Reagents:*

1 pint reagent 41, K
1 quart reagent 42, K
1 quart reagent 43, K
1 pint reagent 44, K

*Equipment:*

1 volumetric pipette, Exax, 20 ml., for transferring aliquots of sugar extract
12 Pyrex beakers, 250 ml.
12 watch glasses, 3½″-diameter, to cover 250-ml. beakers
*Note:* An electric refrigerator should be available within easy access of laboratory for cooling and storing speciments, and ice-cold distilled water and distilled water ice cubes required in the procedure.
1 Mohr pipette, Exax, 5 ml., for reagent 41, K
12 glass stirring rods, 6″-length
12 Gooch crucibles, 20 ml.
1 asbestos stamper
1 crucible holder for Gooch crucibles
10 grams asbestos specially prepared for this determination
1 filter pump, brass, ⅜″ pipe thread with ⅜″ coupling.
1 filtering flask, 1000 ml., with side tube and 3-ft. length of rubber tubing
1 screw-cap chemical bottle (1½ to 2-liter capacity) provided with opening in cover for siphon
1 glass siphon (5 mm. glass tubing, with 3-ft. length of rubber tubing fitted with glass nipple and stopcock)
2 burettes, Exax, 50 ml., for reagents 43, K and 44, K
2 support stands, iron, 6 x 9″ with rods } for 50-ml. burettes
2 Lincoln burette clamps }
1 special pipette, 5 ml., for reagent 42, K
1 electric heater (any type available) or Bunsen burner

*Procedure:*

*Note:* This analysis must be conducted in duplicate and in a laboratory that is free from ammonia fumes.

1. Mix the 500 ml. of sugar extract thoroughly and pipette 20 ml. into a clean 250-ml. beaker.

2. Cover the beaker with a watch glass and cool to 10° C. (or lower) in refrigerator.

3. Add 5 ml. of reagent 41, K by means of a 5-ml. Mohr pipette, stirring the solution vigorously with a glass rod. Place the beaker in the refrigerator overnight; allow glass rod to remain in beaker and cover the beaker with a watch glass.

4. Set up a Gooch filter, as follows:

(*a*) Prepare an asbestos suspension by mixing five grams of specially prepared asbestos and one liter of distilled water. Keep the mixture in a covered jar. Before using, shake the asbestos mixture to get a homogeneous suspension, and pour immediately a convenient quantity into a beaker.

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*** An adaptation of: Volk, N. J., and Truog, E., 1934. A rapid chemical method for determining the readily available potash of soils. Jour. Am. Soc. Agr., 26: 537–546.**

(*b*) Fit the crucible holder to the filtering flask. Place the crucible in the receptacle of the crucible holder. Pour asbestos (stir well before each pouring with a glass rod) into the crucible about ¾ full, and let the water drain through for a few seconds without suction.

(*c*) Then apply suction. Immediately, after the excess water is drawn out, compact the asbestos by stamping several times with the stamper.

(*d*) Again pour additional asbestos suspension into the crucible to about ¼ capacity and compact the pad as before. Wash the asbestos felt which will be formed with distilled water several times. Examine the asbestos felt, holding the crucible up to the light. If no light comes through the bottom (pad too thick) or if the openings are too plainly seen (pad too thin), the mat must be discarded and a new one prepared.

*Note:* Do *not* dispose of asbestos. It may be used over and over again after purification. Purification may be accomplished by washing, through suction, several times with distilled water. Return to original jar. Add sufficient distilled water to have approximately the original asbestos concentration (five grams per liter).

5. Arrange for a supply of ice-cold distilled water (10° C. or lower). Prepare a tray of ice cubes using distilled water. Place cold water in chemical jar. (This may be accomplished by leaving the distilled water in the jar in the refrigerator overnight and then adding a few distilled-water ice cubes to it just before using.) Insert siphon through the hole in the cover.

6. Transfer contents of cold beaker (which has stood overnight in refrigerator) to the prepared crucible. The precipitate will collect on the mat in the Gooch crucible. Wash beaker and stirring rod with a few ml. of ice-cold distilled water. Use only enough to rinse the sides of the beaker with a thin film. Transfer washings to the Gooch crucible. Repeat the washing of beaker and rod with transfer of washings to Gooch crucible *five successive times.* It is very important to hold the total volume of wash water used to the smallest possible quantity. Now wash the Gooch crucible *five additional times* using only a few ml. of ice-cold distilled water for the entire operation. Wash outside of Gooch crucible with a little of the ice-cold distilled water after removing from the holder.

*Note:* In transferring the solution from the beaker to the crucible, use a glass stirring rod held securely against the lip of the beaker. The stirring rod, down which the liquid runs, should never be drawn up in such a way as to allow the solution to collect on the under side of the lip of the beaker. In washing, the stream of distilled water should always be directed around the upper edge of the crucible, and wash water should always be allowed to drain to the last drop after each addition.

7. Loosen the asbestos pad carefully with the stirring rod and place Gooch crucible and rod into original beaker.

8. Add enough hot distilled water (at about boiling point) to cover the Gooch crucible.

9. Carefully noting the volume used add, first, a few ml. of reagent 43, K from burette and follow immediately with 5 ml. of reagent 42, K using the special 5-ml. pipette. Do not allow the purple color to fade out. Stir the mixture vigorously to break up the asbestos pad. Continue to add reagent 43, K until an excess of reagent remains.

10. Place the beaker with contents on an electric heater (or over a low flame)

and heat to boiling. (Stirring may be necessary to prevent bumping.) If the purple color begins to disappear, add more reagent 43, K immediately from the burette. (Remember that the burette reading will be noted later.)

11. Remove the beaker from the heater and add 2 ml. of reagent 44, K from its burette, while stirring. The purple color should disappear. If not, then continue with a few drops of reagent 44, K in excess of the fading point.

12. Add reagent 43, K (drop by drop while stirring) to the end point.

*Note:* The end point is obtained when one drop of reagent 43, K in excess imparts a distinct pink color to the solution which does not fade for one minute.

13. Read both burettes to the nearest 0.05 ml.

*Note:* In reading the burettes, read the *top* of the meniscus for reagent 43, K and the *bottom* of the meniscus for reagent 44, K. The eyes should be directly opposite the point read.

14. Subtract ml. of reagent 44, K from ml. of reagent 43, K to obtain a net ml. of reagent 43, K. (Make a blank determination on each lot of asbestos, and if the titration figure is appreciable, subtract it from the net ml. of reagent 43, K.)

15. Take the average ml. of reagent 43, K of the duplicate determinations and refer to the Table of Per Cent Potassium in Cane Sheath Material.

*Note:* If the difference in ml. of reagent 43, K used between duplicates exceeds 0.30 ml., discard the result and repeat the analysis.

.20 ml. = .03% .30 ml. = .05% .40 ml. = .07%

16. Refer to the Table of Factors for Potassium Index.

17. Per Cent K × Factor = K Index.

*Example:*

Ml. of reagent 43, K = 12.75 ml.
Referring to Table of Per Cent K, 12.75 ml. of reagent 43, K = 2.08%.
Per cent sugar (from analysis) = 15.55.
Referring to Table of Factors for Potassium Index, Factor = 1.18.
Then, Per Cent K × Factor = K Index, or 2.08 × 1.18 = 2.45%.

### TABLE OF PER CENT K IN CANE SHEATH MATERIAL

% K = .1630 × ml. of reagent 43, K on the basis of 5-gram sample (dry wt.)

| A | | B | |
|---|---|---|---|
| ml. of reagent 43, K | Per cent K | ml. of reagent 43, K | Per cent K |
| .05 | .01 | 1.00 | .16 |
| .10 | .02 | 2.00 | .33 |
| .15 | .02 | 3.00 | .49 |
| .20 | .03 | 4.00 | .65 |
| .25 | .04 | 5.00 | .82 |
| .30 | .05 | 6.00 | .98 |
| .35 | .06 | 7.00 | 1.14 |
| .40 | .07 | 8.00 | 1.30 |
| .45 | .07 | 9.00 | 1.47 |
| .50 | .08 | 10.00 | 1.63 |
| .55 | .09 | 11.00 | 1.79 |
| .60 | .10 | 12.00 | 1.96 |
| .65 | .11 | 13.00 | 2.12 |
| .70 | .11 | 14.00 | 2.28 |
| | | 15.00 | 2.44 |
| | | 16.00 | 2.61 |
| | | 17.00 | 2.77 |
| | | 18.00 | 2.93 |
| | | 19.00 | 3.10 |
| | | 20.00 | 3.26 |
| | | 21.00 | 3.42 |

## TABLE OF PER CENT K IN CANE SHEATH MATERIAL (*Continued*)

**% K = .1630 X ml. of reagent 43, K on the basis of 5-gram sample (dry wt.)**

| A | | B | |
|---|---|---|---|
| ml. of reagent 43, K | Per cent K | ml. of reagent 43, K | Per cent K |
| .75 | .12 | 22.00 | 3.59 |
| | | 23.00 | 3.75 |
| .80 | .13 | 24.00 | 3.91 |
| | | 25.00 | 4.08 |
| .85 | .14 | 26.00 | 4.24 |
| | | 27.00 | 4.40 |
| .90 | .15 | 28.00 | 4.56 |
| .95 | .15 | 29.00 | 4.73 |
| | | 30.00 | 4.89 |
| 1.00 | .16 | 31.00 | 5.05 |

**To obtain % K when the volume of reagent 43, K exceeds 1 ml., locate the value of % K corresponding to a fraction of 1 ml. from Column *A*, and add it to the proper value of % K in Column *B*.**

***Example:***

**ml. of reagent 43, K = 12.55.**

**12.00 ml. (Col. B) + .55 ml. (Col. A) = 1.96% K + .09% K = 2.05% K.**

***Note:*** **When a 10-gram sample is used for sugar extraction, indicated percentage (from table) should be divided by two.**

## TABLE OF FACTORS FOR POTASSIUM INDEX

$$\text{Factor (F)} = \frac{100}{100 - \%\ \text{sugar}}$$

| % sugar range | Factor | % sugar range | Factor | % sugar range | Factor |
|---|---|---|---|---|---|
| 0.0–0.4 | 1.00 | 11.9–12.6 | 1.14 | 22.2–22.7 | 1.29 |
| 0.5–1.4 | 1.01 | 12.7–13.4 | 1.15 | 22.8–23.3 | 1.30 |
| 1.5–2.4 | 1.02 | 13.5–14.1 | 1.16 | 23.4–23.9 | 1.31 |
| 2.5–3.3 | 1.03 | 14.2–14.8 | 1.17 | 24.0–24.5 | 1.32 |
| 3.4–4.3 | 1.04 | 14.9–15.6 | 1.18 | 24.6–25.0 | 1.33 |
| 4.4–5.2 | 1.05 | 15.7–16.3 | 1.19 | 25.1–25.6 | 1.34 |
| 5.3–6.0 | 1.06 | 16.4–17.0 | 1.20 | 25.7–26.1 | 1.35 |
| 6.1–6.9 | 1.07 | 17.1–17.7 | 1.21 | 26.2–26.7 | 1.36 |
| 7.0–7.8 | 1.08 | 17.8–18.3 | 1.22 | 26.8–27.2 | 1.37 |
| 7.9–8.6 | 1.09 | 18.4–19.0 | 1.23 | 27.3–27.7 | 1.38 |
| 8.7–9.5 | 1.10 | 19.1–19.6 | 1.24 | 27.8–28.3 | 1.39 |
| 9.6–10.3 | 1.11 | 19.7–20.3 | 1.25 | 28.4–28.8 | 1.40 |
| 10.4–11.1 | 1.12 | 20.4–20.9 | 1.26 | 28.9–29.3 | 1.41 |
| 11.2–11.8 | 1.13 | 21.0–21.5 | 1.27 | 29.4–29.8 | 1.42 |
| | | 21.6–22.1 | 1.28 | 29.9–30.3 | 1.43 |

## THE PHOSPHORUS INDEX BY RCM*

*Reagents:*

1 quart reagent 51, P
½ gallon reagent 52, P
¼ pint reagent 53, P
½ pint reagent 54, P
½ pint ammonium molybdate solution (9.6 *N*)
½ pint stannous chloride solution
1 pint standard phosphate solution (5 p.p.m. P.)

*Equipment:*

1 Bunsen burner
1 electric muffle
6 type "H" electric heaters
1 student-type analytical balance, sensitive to 0.1 mg.

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*** An adaptation of: Truog, Emil, and Meyer, A. H., 1929. Improvements in Denigès colorimetric method of phosphorus and arsenic. Ind. and Eng. Chem. (Analytical Ed.) 1: 136–139.**

1 balance scoop, aluminum, 30 ml., with counterpoise
6 porcelain crucibles, 30 ml.
6 beakers, Pyrex, 600 ml.
6 volumetric Pyrex flasks, 500 ml.
12 Erlenmeyer Pyrex flasks, 125 ml., narrow mouth
1 graduated cylinder, Exax, 10 ml., for reagent 52, P
1 graduated cylinder, Exax, 50 ml., for distilled water
1 graduated cylinder, Exax, 100 ml., for preparation of standard solution
6 Nessler tubes, short form, 100 ml.
6 glass funnels, 65-mm. diameter
1 volumetric pipette, Exax, 5 ml., for transferring stock solution
1 Mohr pipette, Exax, 10 ml., for reagent 51, P and ammonium molybdate solution
1 volumetric pipette, Exax, 10 ml., for transferring aliquots of prepared sample
1 volumetric pipette, Exax, 5 ml., for transferring aliquots of prepared sample
1 volumetric pipette, Exax, 3 ml., for transferring aliquots of prepared sample
6 glass rods, 7″-length
A small supply of white typing paper
1 pair crucible tongs, nickel, 9″-length
1 dropping bottle, pipette stopper, 60 ml., for stannous chloride solution
1 dropping bottle, pipette stopper, 60 ml., for reagent 53, P
1 bottle, ¼-pint capacity, paraffin-coated, rubber stopper with dropper fitted, for reagent 54, P
6 triangles, wire, 2″
6 rubber policemen

*Procedure:*

1. Weigh out one gram of the ground and dried sheath specimen in a balance scoop; transfer to a porcelain crucible.

2. Add 2 ml. of reagent 51, P using a 10-ml. Mohr pipette.

3. Ash on type "H" electric heater in the following manner: Reverse heater refractory so that its bottom or flat surface faces upward. Place the crucible, supported by triangle, in hole of refractory. Turn on heater and ash for ½ hour.*

*Note:* Disconnect heater after each ashing operation; allow heater to cool before ashing additional samples.

4. Remove crucible from heater and allow it to cool. Moisten ash with a few ml. of distilled water to avoid spattering. Using a 10-ml. graduated cylinder, add 10 ml. reagent 52, P to the residue; let stand for at least one hour.

5. Transfer (through a 65-mm. funnel) the entire contents of the crucible into a 500-ml. volumetric flask. Scrub inside of crucible with rubber policeman and wash the inside of the crucible repeatedly with distilled water; make up to volume (500 ml.).

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*** For purposes of RCM, this procedure (Step No 3) will be found more suitable and efficacious. However, in regular, established laboratories, the following method may be followed: Ignite with gas flame. When alcohol has been consumed, warm crucible cautiously and gently over gas flame (low heat) until ignition is complete. Ash overnight in electric muffle at red heat or lower (below 800° C.).**

6. Pour into 600-ml. beaker and mix thoroughly, using a glass stirring rod. Allow solution to stand for a few moments to permit insoluble material to settle.

7. Pour slowly (decant) the clear supernatant solution back into the 500-ml. volumetric flask; discard material remaining in beaker.

8. Using a 5-ml. volumetric pipette, transfer a 5-ml. aliquot (take a 10-ml. aliquot if phosphorus concentration of sample is low; if phosphorus concentration is high, use a 3-ml. aliquot) into a 125-ml. Erlenmeyer flask and dilute to 50 ml. with distilled water, using a 50-ml. graduated cylinder.

9. Add one drop of reagent 53, P, and reagent 54, P (drop by drop) until color of the test solution becomes just faintly yellow.

10. Add two ml. of ammonium molybdate solution with a 10-ml. Mohr pipette and mix well (swirling motion).

11. Add three drops of stannous chloride solution from dropping bottle. Compare with standard solution, as follows:

*Note:* Standard solution should be prepared before completion of Step No. 11. See Step No. 12 for preparation of standard solution.

(*a*) Transfer the contents of the Erlenmeyer flask containing the unknown (test solution) into a 100-ml. Nessler tube. Standard solution remains in 100-ml. graduated cylinder.

(*b*) Hold the Nessler tube containing the test solution, together with an empty Nessler tube, in one hand over a white background. (Fold a sheet of white typing paper in half, lengthwise, and stand it up on both edges. Then hold Nessler tubes so that the tube bottoms are bisected by the crease in the paper.)

(*c*) Pour the standard solution from the graduated cylinder into the empty Nessler tube until the colors match when sighted from the top of the tubes. If an excess of standard solution is added, pour it back into the graduated cylinder and repeat the matching operation.

*Note:* If possible, use a constant source of white light in matching colors.

(*d*) Take reading of cylinder to ascertain amount of standard which you were required to use in operation (*c*).

*Note:* Standard solution in Nessler tube is poured back into graduated cylinder for subsequent comparisons during this analytical run only. Discard the standard solution when analyses are complete.

12. Prepare standard solution as follows: Using a 5-ml. volumetric pipette, transfer exactly 5 ml. of the stock solution (5 p.p.m. P) into a 100-ml. graduated cylinder. Dilute to 96 ml. with distilled water; add 4 ml. ammonium molybdate solution (using a 10-ml. Mohr pipette). Transfer to a 125-ml. Erlenmeyer flask and mix well (swirl contents of flask). Add six drops of stannous chloride solution from dropping bottle and mix well. A maximum blue color should develop almost immediately. The standard solution, containing 0.25 p.p.m. P, is now ready for use.

*Note:* Since the blue color developed in the standard solution will start to fade after standing about 10 minutes, a new standard should be made up accordingly.

13. Refer to table and determine percentage of Phosphorus in sample.

## TABLE OF PERCENTAGES OF PHOSPHORUS IN DRIED CANE SHEATH MATERIAL

| Ml. standard required | Ml. aliquots taken | | | | | |
|---|---|---|---|---|---|---|
| | 3 ml. | | 5 ml. | | 10 ml. | |
| | p.p.m. | % | p.p.m. | % | p.p.m. | % |
| 20 | 833 | .08 | 500 | .05 | 250 | .03 |
| 21 | 875 | .09 | 525 | .05 | 263 | .03 |
| 22 | 917 | .09 | 550 | .06 | 275 | .03 |
| 23 | 958 | .10 | 575 | .06 | 288 | .03 |
| 24 | 1000 | .10 | 600 | .06 | 300 | .03 |
| 25 | 1042 | .10 | 625 | .06 | 313 | .03 |
| 26 | 1083 | .11 | 650 | .07 | 325 | .03 |
| 27 | 1125 | .11 | 675 | .07 | 338 | .03 |
| 28 | 1167 | .12 | 700 | .07 | 350 | .04 |
| 29 | 1208 | .12 | 725 | .07 | 363 | .04 |
| 30 | 1250 | .13 | 750 | .08 | 375 | .04 |
| 31 | 1292 | .13 | 775 | .08 | 388 | .04 |
| 32 | 1333 | .13 | 800 | .08 | 400 | .04 |
| 33 | 1375 | .14 | 825 | .08 | 413 | .04 |
| 34 | 1417 | .14 | 850 | .09 | 425 | .04 |
| 35 | 1458 | .15 | 875 | .09 | 438 | .04 |
| 36 | 1500 | .15 | 900 | .09 | 450 | .05 |
| 37 | 1542 | .15 | 925 | .09 | 463 | .05 |
| 38 | 1583 | .16 | 950 | .10 | 475 | .05 |
| 39 | 1625 | .16 | 975 | .10 | 488 | .05 |
| 40 | 1667 | .17 | 1000 | .10 | 500 | .05 |

14. Find the factor for phosphorus index. (Refer to Table of Factors for Potassium Index.)

15. Per cent Phosphorus X Factor = Phosphorus Index.

*Example:*

A 5-ml. aliquot requires 26 ml. of standard solution.

Referring to table above, percentage of P = .07%.

Per cent of sugar (by analysis) = 12.53%.

Referring now to Table of Factors for Potassium Index, Factor = 1.14.

Then, per cent P X Factor = Phosphorus Index, or .07% X 1.14 = .08%.

*Important Precautions:* Arsenic produces exactly the same color as phosphorus in colorimetric analyses of this character. Pyrex glassware contains a small amount of arsenic oxide, so that the use of *new* Pyrex vessels may cause serious contamination. All glassware should, therefore, be treated with warm sulfuric-acid-dichromate solution for at least 24 hours. After this treatment, wash glassware and then rinse thoroughly with distilled water.

*Note:* The RCM division of the Chemistry department will furnish glassware treated as noted above upon request. A small charge will be made to cover the cost of this service.

Results which appear to be questionable should be checked by redeterminations.

### PREPARATION OF REAGENTS

*Reagent 41, K (Sodium Cobaltinitrite Solution)*:

Dissolve 150 gm. of sodium cobaltinitrite, C P powder ($Na_3CO(NO_2)_6$) in 500 ml. of distilled water. When in solution, filter through asbestos on a Gooch crucible and keep in the refrigerator in tightly closed, glass-stoppered amber bottle. (This reagent may keep for several months; occasional checking is required.)

*Reagent 42, K (Dilute Sulfuric Acid Solution, 1 + 4; 7.2 Normal)* :

Add one volume of concentrated sulfuric acid to four volumes of distilled water.

*Reagent 43, K (Standard 0.05 Normal Potassium Permanganate Solution)* :

Dissolve 3.5 gm. of potassium permanganate, CP crystals in about one liter of distilled water, digest at or near the boiling point for a few hours, cool and allow to stand two or three days. Filter the solution through asbestos and make up to two liters. Standardize against $Na_2C_2O_4$. ($Na_2C_2O_4$ is dried at 120° C. overnight; 3.35 gm./liter = 0.05 Normal.)

*Reagent 44, K (Standard 0.05 Normal Oxalic Acid)* :

Dissolve 6.31 gm. of $H_2C_2O_4 \cdot 2H_2O$ in distilled water and make up to two liters. Standardize by titrating the oxalic acid, hot (at about boiling point), with 0.05 Normal standard potassium permanganate solution.

*Asbestos (Medium Fiber, Powminco, Washed in Acid)* :

Digest the asbestos in dilute nitric acid (one part of acid to ten parts of distilled water) containing just sufficient potassium permanganate to give a deep purple color. Add more permanganate if the color disappears, and digest for at least 24 hours and until the permanganate color is permanent. Destroy any excess permanganate with oxalic acid, after which the asbestos should be pure white. Wash thoroughly on a Buchner funnel.

*Reagent 45, S (Phenolphthalein Indicator)* :

Dissolve one gm. of phenolphthalein in 100 ml. of alcohol, 95 per cent by volume.

*Reagent 46, S (20 Per Cent NaOH Solution)* :

Dissolve 20 gm. sodium hydroxide, CP pellets in distilled water and make up to 100 ml. with distilled water.

*Reagent 47, S (Standardized Copper Sulfate Solution)* :

Dissolve 139 grams of CP copper sulfate crystals ($CuSO_4 \cdot 5H_2O$) in distilled water and make up to two liters with distilled water.

*Standardization:* Neutralize 50 ml. of the standard invert sugar solution in a 250-ml. volumetric flask with dilute sodium hydroxide and make up to the mark with distilled water. Pipette five ml. of the alkaline tartrate solution into a 300-ml. Erlenmeyer flask and from an accurate burette measure in exactly five ml. of the copper sulfate solution. Then from a burette run in 24 ml. of the neutralized standard invert sugar solution. Place on an open-top electric hot plate which has been covered by a very thin sheet of asbestos and heat to boiling. Continue the boiling for exactly two minutes and then add five drops of the methylene blue solution. Continue boiling and finish the titration by adding the invert sugar solution from the burette, a few drops at a time, until the blue color just disappears. This titration should require 25.64 ml. of the invert sugar solution. If it takes less than the required amount (25.64 ml.), the copper solution is weak and more of the copper salt must be added to bring it to the required strength. If it takes more than 25.64 ml., the copper solution is too strong and must be diluted to bring it to the proper strength.

*Example:*

Titration required, 26.40 ml.

Then: $\frac{26.40}{25.64} = 1.0296$ or 29.6 ml. of distilled water per 1,000 ml. of solution must be added to bring the copper solution to the proper strength.

Original quantity of copper solution, 2000 ml.; used 26.4 ml.

Then: $2{,}000 - 26.4 = 1{,}973.6$ ml.

$29.6 \times \frac{1973.6}{1000} = 58.4$ ml. of distilled water to be added to the 1973.6 ml. of copper solution.

*Standard Invert Sugar Solution:*

Weigh out exactly 9.5 gm. of the best refined sugar obtainable (Con. A), place in a small flask, add five ml. of concentrated HCl and make up to about 100 ml. Allow to stand two or three days if the temperature is over 20° C. (68° F.), or a week if the temperature is below 20° C. Then, without neutralizing, make up to one liter and keep in a well-stoppered bottle. This solution is sufficiently acid to prevent development of microorganisms and will keep for a considerable time. One hundred ml. of this solution contains one gram of invert sugar.

*Reagent 48, S (Alkaline Tartrate Solution):*

Dissolve 692 gm. of CP potassium sodium tartrate crystals and 200 gm. of CP sodium hydroxide pellets in distilled water. Cool and dilute to two liters.

*Reagent 49, S (One Per Cent Methylene Blue Solution):*

Dissolve one gm. of a good grade of methylene blue in 100 ml. of distilled water.

*Reagent 50, S (6 Normal HCl):*

Add one volume of CP HCl to one volume of distilled water.

*Reagent 51, P ($Mg(NO_3)_2$ in Alcohol Solution):*

Dissolve 1000 gm. of magnesium nitrate in 2500 ml. of 95 per cent alcohol.

*Reagent 52, P (2 Normal $H_2SO_4$):*

Take 115 ml. of concentrated 36 Normal sulfuric acid (arsenic and phosphorus-free) and make up to two liters with distilled water.

*Reagent 53, P (2,4 Dinitrophenol):*

A saturated solution of 2,4 dinitrophenol.

*Reagent 54, P (10 Per Cent NaOH):*

Dissolve 200 gm. of CP sodium hydroxide pellets in about 1000 ml. of distilled water. Make up to two liters when the solution has cooled.

*Ammonium Molybdate Solution (9.6 Normal):*

Dissolve 100 gm. of ammonium molybdate in 800 ml. of distilled water heated to 60° C., and filter. Dilute 1100 ml. of arsenic- and phosphorus-free concentrated

$H_2SO_4$ to 3200 ml. After both solutions have cooled, add the ammonium molybdate solution slowly, with constant shaking, to the sulfuric acid solution. Cool to room temperature and dilute to exactly 4000 ml. This is approximately a 9.6 Normal solution of $H_2SO_4$ containing 2.5 gm. of ammonium molybdate per 100 ml.

*Standard $KH_2PO_4$ Solution (Five Parts Per Million P):*

Dissolve 0.2195 gm. of $KH_2PO_4$ in distilled water and dilute to one liter. This solution contains 50 parts per million of phosphorus and serves as the base stock solution. Prepare standard phosphate solution by taking 50 ml. of the base stock solution and diluting to 500 ml. with distilled water. This standard solution contains five parts per million of phosphorus.

## EXPERIMENT STATION CHECKING SYSTEM

At regular intervals representative portions of analyzed specimens should be forwarded to the Chemistry department, Experiment Station, H.S.P.A., with plantation data. A checking analysis of each specimen will be made at the Experiment Station, the results will be compared with the plantation findings and recommendations forwarded to the plantation based upon the results of the checking study.

Reagents and equipment identical to those used on the plantations are employed in such checking studies. This service is offered gratis as a part of the cooperation tendered by the Experiment Station.

# Sugar Prices

## 96° CENTRIFUGALS FOR THE PERIOD MARCH 16, 1944, TO JUNE 15, 1944

| Date | Per pound | Per ton | Remarks |
|---|---|---|---|
| March 16, 1944–June 15, 1944 | 3.74¢ | $74.80 | Philippines |

THE HAWAIIAN
PLANTERS' RECORD

Vol. XLVIII FOURTH QUARTER 1944 No. 4

*A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.*

# Weed Control: Sodium Chlorate as a Herbicidal Agent in Pastures

By Francis E. Hance

*Ingestion of about one pound of sodium chlorate by a full-grown steer has been found fatal to the animal. In spite of this fact, controlled chlorate spraying in pastures to destroy weeds need occasion no harm to grazing animals nor constitute any other serious hazard. The subject is discussed very briefly. Authoritative recommendations are quoted from mainland research workers for using and handling chlorates. Further suggestions are submitted.*

Sodium chlorate is employed extensively on the mainland and to an appreciable extent in Hawaii in controlling weed growth and other obnoxious plants in pasture lands and on ranches.

In view of the fact that this chemical is ordinarily reduced to common salt in the presence of organic matter and moisture, it has been classed as harmless to animals after its application in the field.

It has been noted in Hawaii that for several days following a chlorate spraying on tall grass the fire hazard is distinctly increased and that a flame or spark applied to a spot in the dried, treated area is rapidly and, in some cases, explosively transmitted to the rest of the dried matter in the sprayed section. To circumvent the accidental combustion of chlorate-sprayed vegetation it has been the custom to include an amount of calcium chloride in the spray solution equal to the weight of chlorate used. The hygroscopic nature of the chloride, of course, retains sufficient moisture on the sprayed plants to act as a retardent of spontaneous or vigorous combustion. Hence it appears likely that the reduction of the major portion of sodium chlorate to sodium chloride on the sprayed plants takes place only after a contact period of several days—perhaps a week, or even longer.

Recently, in Hawaii, experimental studies on the eradication of fire bush in pastures have developed a technic of applying dry sodium chlorate on the soil directly at the base of the bush, and in contact with the incised main stem or trunk of the plant.

In discussing this subject with Dr. J. M. Hendershot, Chief, Department of Bacteriology and Pathology, Board of Agriculture and Forestry, Territory of Hawaii, he pointed out the danger of indiscriminate use of sodium chlorate in areas where grazing animals might have access to the chemical, on or off vegetation, before it had been reduced to table salt—as it is—in its herbicidal function. Dr. Hendershot cited previous experiences he had gained on the mainland in clinical studies of the effects of ingested chlorates on grazing animals and submitted several recent papers by former colleagues dealing with the problem.

It has been stated here previously that sodium chlorate persists unaltered for some time on sprayed vegetation. The saline taste of the chemical makes it attractive to the animal. Moore (4) of the Department of Surgery and Medicine, Kansas State College, observes that apparently little, if any, reduction of chlorate to chloride occurs in the body of the animal and hence its poisonous effect continues even to the point where partial elimination occurs in the urine. He adds that absorption in the animal is rapid and the toxic action is violent and prolonged. Where elimination is impeded, chlorates produce an actual asphyxia when about 75 per cent of the blood hemoglobin has been affected.

Laird (2) explains that there are indications that the injurious action of chlorates on animals may be due to their combination with hemoglobin of the blood to form methemoglobin, thus diminishing the oxygen-transporting power of the blood stream.

McCulloch and Murer (3) in a discussion on the subject point out that while it is true that livestock can consume moderate amounts of chlorate-treated weeds without harm this fact in itself (and generally recognized) has occasioned a certain amount of carelessness in handling and distributing the chemical. They reiterate essentially the same observation made previously here, *i.e.*, that the harmless nature of chlorate-sprayed vegetation (when it is harmless) may be dependent upon vital time and chemical environmental elements which carry the chlorate on the weed surfaces entirely or principally to the inocuous salt, sodium chloride.

McCulloch and Murer (3) have published a recommendation to live stock growers on the use of chlorates. Their advice is practical, straightforward and makes good chemical sense. It follows:

"It was recommended that the use of sodium chlorate in the control of noxious weeds be continued, but that the following precautions be taken:

"1. The range be heavily salted at least a week before the sodium chlorate is applied, and the salt be replenished frequently so that plenty will remain in the troughs as long as there is any sodium chlorate on the ground;

"2. all lumps of sodium chlorate either be broken up or dissolved in water;

"3. that only reasonable amounts, *i.e.*, not over 5 pounds per square rod, be applied;

"4. that great care be taken not to spill the chemicals on the ground where cattle would have access to small piles; and

"5. that partially used drums be placed where cattle can not reach them."

Former practice in Hawaii employed sodium chlorate in spray-solution at the rate of one pound of chemical in one gallon of water. As an expedient (*a*) in reducing the costs of preparing chlorate spray solutions, (*b*) in minimizing the fire hazard, (*c*) in making the residue less attractive to animals and (*d*) to take advantage of the synergetic action of the H.S.P.A. Activator* (patent pending) upon the chlorate herbicide, the author (1), in 1940, recommended an activated spray solution for ranchmen in Hawaii which has been used with some success.

A typical activated chlorate spray, containing but one-fifth the chlorate fraction of standard practice and which appears to be equally as effective, is prepared by dissolving 20 pounds of sodium chlorate and 4 pounds of H.S.P.A. Activator in 100 gallons of water. The physical characteristics of the activated solution preclude the necessity of adding to it any "wetting" or "spreading" agents.

In view of the additional hazards of chlorate sprays, as recently reported, it may be suggested that the cheaper and equally effective activated chlorate solutions might prove generally more satisfactory to all stockmen using this chemical in weed control.

## LITERATURE CITED

(1) Hance, Francis E., 1940. The factor of synergism in chemical weed control. The Hawaiian Planters' Record, 44: 263–272.

(2) Laird, Glover, 1941. Sodium chlorate poisoning in cattle. Veterinary Medicine, 36: 318–319.

(3) McCulloch, Ernest C., and Murer, H. K., 1939. Sodium chlorate poisoning. Journ. of the Amer. Veterinary Medical Assn., 95: 675–682. Also published as scientific paper No. 393, College of Agri. and Expt. Stn., State College of Washington.

(4) Moore, G. R., 1941. Sodium chlorate poisoning in cattle. Journ. of the Amer. Veterinary Medical Assn., 99: 50–52.

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* The sodium salt of pentachlorophenol.

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# Leaf-punch Nitrogen Studies on First Ratoon Crop of 32–8560 at Waipio

By M. Doi

*An attempt has been made to develop an index of the nitrogen requirement of sugar cane in a study of the progressively changing nitrogen fraction in the blades of the plant at frequent intervals during its growing cycle. The progress of the research is discussed, together with the difficulties encountered in accurately appraising the observations and data, and in finding therein the groundwork for a reliable criterion in the control of fertilization with this nutrient.*

Three field experiments at Waipio, Oahu (Experiments 108 ATN, 109 N and 110 AN) are cooperative studies related to the nitrogen nutrition of sugar cane. One of the objectives of these tests is the evaluation of the leaf-punch technic as a criterion for nitrogen fertilization.

According to usual plantation practice, nitrogen fertilization control is based mainly upon results of field experiments which are carried out with predetermined amounts of nitrogen applied in accordance with fixed schedules. The results of the different treatments are studied to determine the optimum application and also to estimate the nitrogen fertilization for the succeeding crop. However, results obtained from a series of these experiments have generally indicated that the optimum treatment is not constant. Variable results are caused to a large extent by the meteorological variations which occur from year to year (3, 6).

The system of fertilization control by leaf-punch nitrogen analyses, by determining the nitrogen content in the active leaf tissues at various chronological stages of crop development, seeks to have the plant indicate its nutrient requirement. This method of determining the nitrogen needs of sugar cane was proposed by Yuen and Hance (8) on the basis of the relationships established by them as existing between the nitrogen levels in the leaf samples and growth (elongation) of cane, and the correlation which they found exists between the percentage of nitrogen in the leaves and the fertilizer applied. The objective of the control is to maintain an optimum balance between growth of cane and sugar storage by controlling nitrogen levels in the leaf tissues according to the levels tentatively established by Yuen and Hance from their studies with H 109 cane. These levels were: an optimum percentage of 2.0 per cent for the initial six months of growth, above which nitrogen appears to be excessive; a minimum percentage of 1.0 per cent, desirable at harvest; and poverty adjustment* between 2.0 and 1.0 per cent. Briefly stated, the plan of control calls for the determination of nitrogen percentages in the leaf-punch samples collected at regular and progressive intervals throughout the growth cycles of a crop. The nitrogen indices thus obtained are plotted against tentative standards and serve as indicators of sufficiency or deficiency of nitrogen at the date of sampling. Interpretation of these data, in the light of other similar results and experiences, serves as a guide in determining the amount of fertilizer to be applied as the crop progresses, as well as the time of fertilization. The nitrogen content of the plant, as indicated by this method of fertilization control, is believed to be directly related to growth (8). Although the leaf-punch nitrogen has been confirmed as a reliable index of the nitrogen levels in the green top of the plant for the Clements' method of crop control (5), the relation of its level alone to the final sugar yield has not been well established (2, 8). The purpose of this paper is to present the results of leaf-punch analyses on the first ratoon crop of 32–8560 cane and to indicate the applicability of the system, proposed as a method for field control of nitrogen, to this particular variety of cane.

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* The theory advanced by Paul Macy in "The quantitative mineral nutrient requirements of plants," *Plant Physiology* 11: 749–764, 1936, on the relationship existing between the percentage content of a nutrient in a plant and the sufficiency of the nutrient for growth, has been proposed for application in a method to determine the mineral requirements of plants by plant analysis. The dominant concept of this theory is a critical percentage of each nutrient in each kind of plant, above which there is luxury consumption and below which there is poverty adjustment which proceeds until a minimum level is reached.

## REVIEW OF THE PLAN

In Experiments 108 ATN and 110 AN, predetermined differential nitrogen applications, both in time and amounts, were made. Results of leaf-punch analyses in these two tests were later correlated with yields and other data. In Experiment 109 N one series of plots (control) received nitrogen fertilization in predetermined amounts, while another series of plots received nitrogen as determined by the system of leaf-punch analyses. These experiments were installed and planted to the variety 32–8560 on August 1, 1940; the plant crop was harvested on May 2–17, 1942 at the age of 21 months.

The first ratoon crop was started on May 25, 1942. The data and discussions which follow refer to Experiment 109 N which was set up for the study of the leaf-punch technic as a method of determining the time and amounts of nitrogen which should be applied to the crop if maximum yields were to be obtained.

Experiment 109 N consisted of seven plots (Treatment "C," or control) in which the predetermined application for the entire crop was 160 pounds of nitrogen per acre, and seven plots (Treatment "L") in which the amounts and time of applying nitrogen were to be determined by the leaf-punch analyses, except that 40 pounds of nitrogen were applied as the presumed initial requirement. Adjacent to this area were three "X" plots which received no nitrogen, the results from which form the basis of this discussion.

## IRRIGATION AND WEATHER DATA

A great deal of attention has been directed toward the "cause and effect" relationships existing between the nitrogen and other growth factors, such as atmospheric energy and water (3, 4, 6). Therefore, irrigation data and accumulated rainfall, and average day-degrees at each monthly sampling interval are presented (Fig. 5) with the hope that these records may render a better and more conclusive interpretation of the leaf-punch data.

## FERTILIZATION

Ammonium sulfate and muriate of potash were applied by hand to the cane row immediately after irrigation, as follows:

| Treatments | Dates and amounts per acre | | | | | | Totals | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1)<br>7/1/42 | (2)<br>9/10/42 | | (3)<br>10/16/42 | (4)<br>10/23/43 | (5)<br>4/14/43 | | | |
| | N | N | $K_2O$ | N | N | N | N | $P_2O_5$ | $K_2O$ |
| C............ | 40 | 60 | 100 | 0 | 60 | 0 | 160 | 0 | 100 |
| L............ | 40 | 60 | 100 | 60 | 0 | 60 | 220 | 0 | 100 |
| X............ | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 100 |

The "C" plots received all of the predetermined amounts of nitrogen in three applications according to fixed schedules. On the other hand, the "L" plots received nitrogen as required by the leaf-punch control, except the first 40 pounds applied as the presumed initial requirement. No phosphate was applied to the crop.

## SAMPLING

The leaf-punch sampling for the first ratoon crop was initiated on July 15, 1942, at the crop age of 1½ months, just two weeks after the first application of 40 pounds of nitrogen fertilization. Thereafter, leaf-punch specimens were taken at regular intervals. The sampling procedure was similar to that of the previous plant crop. A sample was taken from ten primary stalks of which the second, third and fourth visible dewlap leaves were punched. Sixty leaf-punch disks (two disks from each leaf) constituted a sample.

## RESULTS AND DISCUSSION

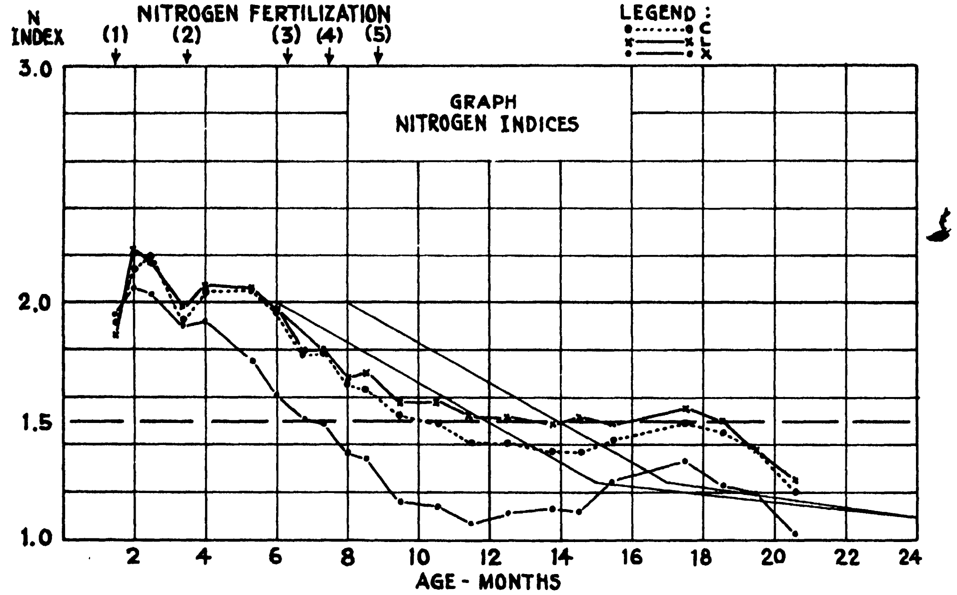
Since the results of leaf-punch studies obtained by previous investigators on the plant crop of Experiment 109 N have not been published, they are presented herein (Table I and Fig. 1) because they are considered relevant in interpreting the results obtained from the first ratoon crop. (For the harvesting results, see Table V.)

### TABLE I

### WAIPIO EXPERIMENT 109 N

Nitrogen Indices of the Plant Crop (Averages for Plots C–L–X)

| Date sampled | Age sampled | Plots | | |
|---|---|---|---|---|
| | | C | L | X |
| 9/10/40 | 5½ weeks | 1.92 | 1.86 | 1.94 |
| 10/1/40 | 2 months | 2.14 | 2.22 | 2.07 |
| 10/15/40 | 2½ " | 2.19 | 2.17 | 2.04 |
| 11/12/40 | 3⅖ " | 1.92 | 1.98 | 1.90 |
| 12/3/40 | 4 " | 2.05 | 2.07 | 1.92 |
| 1/7/41 | 5¼ " | 2.05 | 2.06 | 1.75 |
| 2/3/41 | 6 " | 1.96 | 1.97 | 1.61 |
| 2/24/41 | 6¾ " | 1.78 | 1.79 | 1.51 |
| 3/10/41 | 7⅓ " | 1.79 | 1.80 | 1.49 |
| 3/31/41 | 8 " | 1.65 | 1.68 | 1.36 |
| 4/14/41 | 8½ " | 1.63 | 1.70 | 1.34 |
| 5/12/41 | 9½ " | 1.52 | 1.58 | 1.16 |
| 6/16/41 | 10½ " | 1.49 | 1.58 | 1.14 |
| 7/14/41 | 11½ " | 1.40 | 1.52 | 1.07 |
| 8/11/41 | 12½ " | 1.40 | 1.51 | 1.11 |
| 9/22/41 | 13¾ " | 1.37 | 1.48 | 1.13 |
| 10/13/41 | 14½ " | 1.37 | 1.51 | 1.12 |
| 11/12/41 | 15½ " | 1.42 | 1.49 | 1.25 |
| 1/12/42 | 17½ " | 1.49 | 1.55 | 1.33 |
| 2/18/42 | 18½ " | 1.45 | 1.50 | 1.23 |
| 3/16/42 | 19½ " | 1.38 | 1.37 | 1.19 |
| 4/20/42 | 20½ " | 1.20 | 1.25 | 1.02 |



Fertilization: Pounds Nitrogen per Acre
(Source of nitrogen—ammonium sulfate)

| No. | Date | Plots C | Plots L |
|---|---|---|---|
| 1 | 9/16/40 | 40 | 40 |
| 2 | 11/16/40 | 60 | 60 |
| 3 | 2/10/41 | 0 | 40 |
| 4 | 3/17/41 | 60 | 40 |
| 5 | 4/26/41 | 0 | 40 |
| Total | | 160 | 220 |

Fig. 1. Nitrogen indices and fertilization of the plant crop.

Under the leaf-punch system of controlling the nitrogen levels in cane leaves (8) the initial growth is supposed to be conditioned by maintaining a nitrogen index at approximately two per cent for the first six months. The nitrogen levels should then commence to drop gradually with continued growth of the crop. Finally, the minimum nitrogen level of approximately one per cent is expected to be reached during the period of ripening. With the suggested nitrogen levels and results of leaf-punch studies obtained from the previous plant crop in mind, the nitrogen levels of the first ratoon will now be discussed. (Refer to Table II and Fig. 2.)

The indices of the "C" and "L" plots at the crop age of 1½ months, *i.e.*, two weeks after the initial application of 40 pounds of nitrogen, were about 1.6 per cent —significantly lower than the suggested level of two per cent. However, the index of the "X" plots which received no nitrogen was also approximately 1.6 per cent. It was assumed that the response to 40 pounds of nitrogen was not then realized in the "C" and "L" plots. Therefore, no immediate application of nitrogen was made.

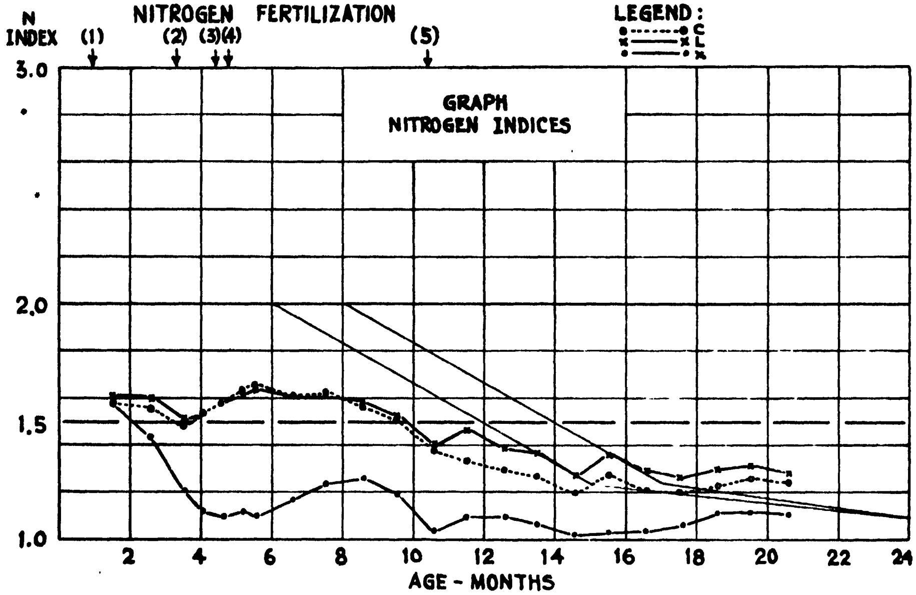
The results of the second sampling, made on August 17, 1942, one month after the first collection, indicated that there was no appreciable lowering of the nitrogen levels in the "C" and "L" plots, but there was a significant drop in the "X" plots. Considering the suggested nitrogen limits (two per cent) for the cane at this age of 2½ months, the index of 1.6 per cent indicated an apparent need for nitrogen at this point. Since the test required that subsequent fertilization of the "L" plots be made by leaf-punch control, it was suggested that at least 60 pounds of nitrogen be applied to the "L" plots immediately. However, the application of nitrogen to the "L" plots was not made until September 10, 1942, when the "C" treatment received its predetermined 60 pounds of nitrogen. This slight delay was due to an acute labor shortage. The 60-pound application of nitrogen increased the nitrogen index from 1.51 per cent, at the age of 3½ months, to 1.58 per cent one month after fertilization —less than a one-tenth per cent rise, and leaving a four-tenths per cent requirement to reach the prescribed level of two per cent. Another 60 pounds of nitrogen was added to the "L" plots at the age of 4½ months on Oct. 16, 1942, in an attempt to boost the nitrogen index. An increase of but 0.04 per cent resulted. The "C" plots received the predetermined 60 pounds of nitrogen by the third and last application on October 23, 1942, one week after the third application was made to the "L" plots. No significant difference in the nitrogen levels was noticed between the "C" and "L" treatments up to the time the fourth application of nitrogen was made to the "L" plots, both treatments having received 160 pounds of nitrogen up to that point. It is worthy of note that the nitrogen index of 1.65 per cent was the maximum for either treatment during the entire period of growth, although the cane had received 160 pounds of nitrogen by the age of 4½ months. The nature of the index curve for the first ratoon is very different from that of the plant crop during the first six months of growth. The nitrogen indices of the "C" treatment (control) of the plant crop, together with those of the first ratoon crop, are presented for comparison both upon the basis of ages (Fig. 3), and on the basis of the month of sampling

TABLE II

WAIPIO EXPERIMENT 109 X

Nitrogen Indices of the First Ratoon Crop (Averages for Plots C–L–X)

| | | Plots | | |
|---|---|---|---|---|
| Date sampled | Age sampled | C | L | X |
| 7/15/42 | 1½ months | 1.58 | 1.61 | 1.57 |
| 8/17/42 | 2½ " | 1.56 | 1.60 | 1.44 |
| 9/14/42 | 3½ " | 1.48 | 1.51 | 1.21 |
| 9/30/42 | 4 " | 1.54 | 1.54 | 1.12 |
| 10/15/42 | 4½ " | 1.58 | 1.58 | 1.10 |
| 11/5/42 | 5⅙ " | 1.63 | 1.62 | 1.12 |
| 11/16/42 | 5½ " | 1.65 | 1.64 | 1.10 |
| 12/15/42 | 6½ " | 1.61 | 1.61 | 1.17 |
| 1/18/43 | 7½ " | 1.62 | 1.61 | 1.24 |
| 2/15/43 | 8½ " | 1.57 | 1.58 | 1.26 |
| 3/15/43 | 9½ " | 1.51 | 1.52 | 1.20 |
| 4/20/43 | 10½ " | 1.38 | 1.40 | 1.04 |
| 5/17/43 | 11½ " | 1.34 | 1.47 | 1.10 |
| 6/15/43 | 12½ " | 1.30 | 1.39 | 1.10 |
| 7/15/43 | 13½ " | 1.27 | 1.37 | 1.07 |
| 8/16/43 | 14½ " | 1.20 | 1.27 | 1.02 |
| 9/15/43 | 15½ " | 1.28 | 1.36 | 1.03 |
| 10/15/43 | 16½ " | 1.21 | 1.29 | 1.04 |
| 11/15/43 | 17½ " | 1.20 | 1.26 | 1.06 |
| 12/16/43 | 18½ " | 1.23 | 1.30 | 1.11 |
| 1/17/44 | 19½ " | 1.26 | 1.32 | 1.12 |
| 2/14/44 | 20½ " | 1.24 | 1.28 | 1.11 |



Fertilization: Pounds Nitrogen per Acre
(Source of nitrogen—ammonium sulfate)

| No. | Date | Plots<br>C | <br>L |
|---|---|---|---|
| 1 | 7/1/42 | 40 | 40 |
| 2 | 9/10/42 | 60 | 60 |
| 3 | 10/16/42 | 0 | 60 |
| 4 | 10/23/42 | 60 | 0 |
| 5 | 4/14/43 | 0 | 60 |
| Total | | 160 | 220 |

Fig. 2. Nitrogen indices and fertilization of the 1st ratoon crop.

(Fig. 4). The "C" treatment, of 160-pound nitrogen application, was considered optimum for the plant crop.

In view of the low nitrogen level in the young ratoon crop, the question of additional fertilization had to be considered. Based on the assumed standards of sufficiency for a 5½-month crop, the leaf-punch nitrogen at 1.64 per cent showed a need for additional fertilization. However, other growth factors had to be considered. The crop was 5½ months of age by the middle of November. Hence it was assumed, in perspective, that growing weather for the following winter months would not be optimum. The leveling off of the nitrogen curve of the "X" or no nitrogen plots was interpreted as a manifestation of unfavorable weather for growth (Figs. 2 and 4). Also considered was the requirement of the previous crop. Since the optimum for the plant crop was believed to be about 160 pounds, and since the quantity of nitrogen added to date to the ratoon totaled 160 pounds, the matter of making further additions of fertilizer was given careful consideration. Moreover, sufficient information not being available concerning the nitrogen levels in leaf-punch specimens of ratooned 32–8560 cane, the decision was made to omit fertilization pending the results obtained at the next sampling period.

The index of 1.6 per cent was approximately maintained from Oct. 15, 1942, to February 15, 1943—a period of four months—at the crop ages of from 4½ to

8½ months. However, the index of the "X" treatment, which had received no nitrogen, rose from 1.10 per cent to 1.26 per cent during the same period. These results differ from those of the plant crop in which the nitrogen indices showed a definite drop in all treatments during the corresponding age period (Fig. 1). It is a matter of interest to note here that there was unusually heavy rainfall during the period from November, 1942, to the middle of January, 1943 (Fig. 5), and that a large portion of the cane lodged.

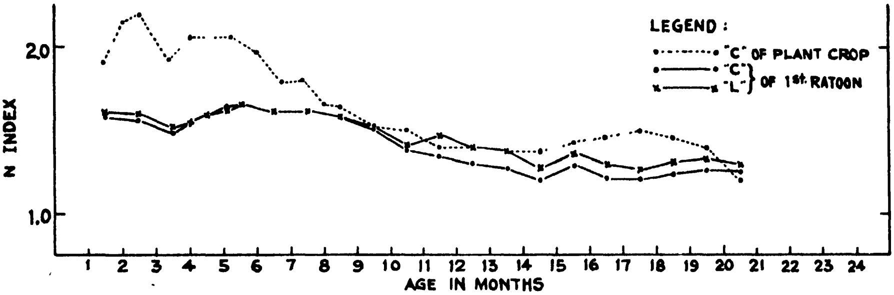


FIG. 3 - NITROGEN INDICES OF 1st RATOON COMPARED WITH "C" (CONTROL) OF PLANT CROP BY AGES

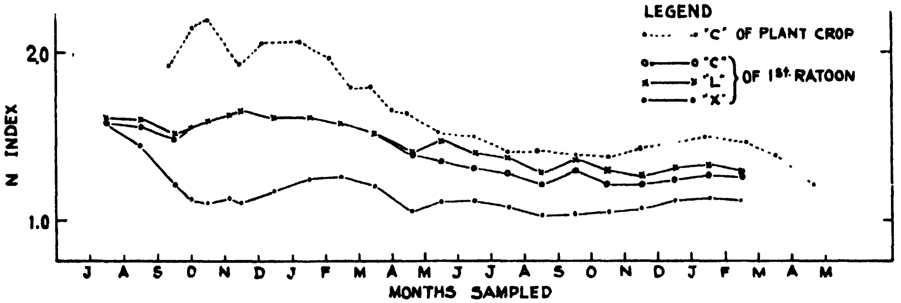


FIG 4 - NITROGEN INDICES OF 1st RATOON COMPARED WITH "C" (CONTROL) OF PLANT CROP BY MONTHS SAMPLED

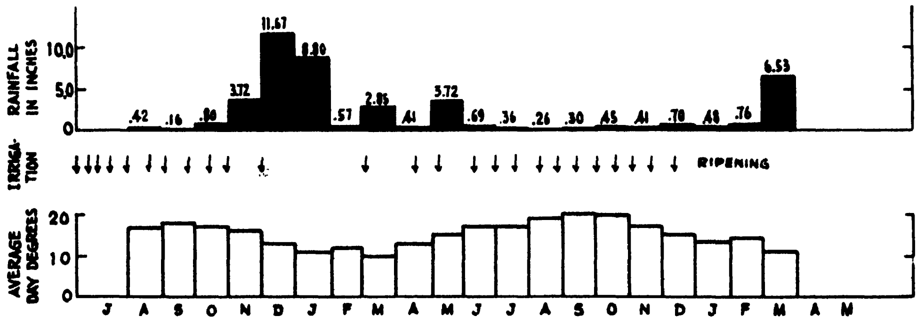


FIG. 5 - IRRIGATION DATA AND AVERAGE DAY-DEGREES AND ACCUMULATED RAINFALL AT MONTHLY SAMPLING INTERVAL

When the spring season set in, the nitrogen level commenced to drop. The index of the "L" plots at 10½ months in April of 1943 was 1.40 per cent, which was almost 0.1 per cent lower than that of the "C" treatment of the plant crop at the corresponding age. When compared according to the time (month) of sampling, this difference would be increased to about 0.2 per cent. (Fig. 4.) The crop still had a considerable period of favorable weather ahead. Therefore, an additional 60 pounds of nitrogen were applied to the "L" plots on April 14, 1943, making the total application 220 pounds, as against 160 pounds for the "C" treatment. The nitrogen level of the "L" plots rose to about 1.5 per cent at 11½ months and then started to drop gradually. However, this additional fertilization was found to be uneconomical, for it did not result in an increase in sugar yield at harvest, 11 months after the last application of nitrogen to the "L" plots (refer to harvesting results in Table IV).

At the time the last 60 pounds of nitrogen were applied to the "L" plots a supplementary leaf-punch study was made on the sucker plants concurrently with the regular sampling. The first series of samples was collected from the suckers (about six feet tall) six days after the nitrogen application; the second series of specimens was taken from the same suckers one month after the first sampling. (A sample was taken from ten sucker plants.) Analytical data thus obtained, together with the results of the regular leaf-punch samples, collected at the corresponding times, are presented in Table III.

TABLE III

COMPARISON OF NITROGEN INDICES OF SUCKERS AND PRIMARY STALKS

Samples Taken on 4/20/43, Six Days After Application of 60 Pounds of Nitrogen to the "L" Plots

| Suckers | | | | Primary Stalks | | | |
|---|---|---|---|---|---|---|---|
| Plots | % T.N. | Plots | % T.N. | Plots | % T.N. | Plots | % T.N. |
| C 41 | 1.46 | L 42 | 1.53 | C 41 | 1.42 | L 42 | 1.44 |
| 43 | 1.42 | 44 | 1.50 | 43 | 1.38 | 44 | 1.43 |
| 45 | 1.48 | 46 | 1.48 | 45 | 1.40 | 46 | 1.37 |
| 48 | 1.51 | 47 | 1.52 | 48 | 1.39 | 47 | 1.43 |
| 49 | 1.43 | 50 | 1.47 | 49 | 1.33 | 50 | 1.38 |
| 52 | 1.49 | 51 | 1.51 | 52 | 1.35 | 51 | 1.39 |
| 53 | 1.49 | 54 | 1.46 | 53 | 1.38 | 54 | 1.36 |
| Aver. | 1.47±.01 | Aver. | 1.50±.01 | Aver. | 1.38±.01 | Aver. | 1.40±.01 |
| Std. deviation | .03 | | .03 | Std. deviation | .03 | | .03 |

Samples Taken on 5/17/43, Approximately One Month After the First Sampling

| Suckers | | | | Primary Stalks | | | |
|---|---|---|---|---|---|---|---|
| Plots | % T.N. | Plots | % T.N. | Plots | % T.N. | Plots | % T.N. |
| C 41 | 1.42 | L 42 | 1.66 | C 41 | 1.30 | L 42 | 1.49 |
| 43 | 1.49 | 44 | 1.70 | 43 | 1.35 | 44 | 1.46 |
| 45 | 1.48 | 46 | 1.55 | 45 | 1.38 | 46 | 1.47 |
| 48 | 1.49 | 47 | 1.63 | 48 | 1.37 | 47 | 1.50 |
| 49 | 1.42 | 50 | 1.62 | 49 | 1.27 | 50 | 1.51 |
| 52 | 1.40 | 51 | 1.67 | 52 | 1.33 | 51 | 1.50 |
| 53 | 1.52 | 54 | 1.53 | 53 | 1.36 | 54 | 1.38 |
| Aver. | 1.46±.02 | Aver. | 1.62±.02 | Aver. | 1.34±.02 | Aver. | 1.47±.02 |
| Std. deviation | .05 | | .06 | Std. deviation | .04 | | .04 |

Reference to Table III reveals that young suckers had a significantly higher nitrogen level than the primary stalks, regardless of the difference in the amount of nitrogen which was applied. Following the application of nitrogen to the "L" plots in April, both the suckers and the primaries increased in per cent total nitrogen. Of interest is the evidence which indicates that the young suckers obtained a much higher percentage of nitrogen than the primaries during the one-month period between April and May. In the "C" plots which received no nitrogen in April there were no significant changes in the nitrogen indices of either the suckers or the primaries. While the data pertaining to sucker plants are not as extensive as might be desired, they appear to indicate that the status of young suckers in a field, when they have a substantial period of growth ahead, should perhaps be given more consideration in determining a critical nitrogen level in the plant, for their inclusion will give a more representative sample from which to evaluate the nitrogen requirement of the crop.

The results of nitrogen determinations on these plant and first ratoon crops of 32–8560 cane raise two important questions: Do the lower nitrogen levels during the period of growth of young 32–8560 cane, when compared with the standards proposed by Yuen and Hance (8), working with H 109 cane, indicate a varietal difference in nitrogen absorption and/or utilization as suggested by Cornelison (7)? Was the failure of the ratoon cane to reach the nitrogen levels of the plant crop during the first nine months of growth due to environmental factors; if not, to what could this failure be ascribed? It is difficult to believe that cane which had received 160 pounds of nitrogen at the age of about five months was insufficiently supplied.

In September, when the crop was about 15 months old, the gradual decline of the nitrogen indices which commenced in the spring and continued throughout the summer stopped and thereafter remained higher than desirable up to the time of the final leaf-punch sampling made in February 1944 at the age of 20½ months. Thus the nitrogen levels on August 15, 1943, were 1.20 per cent for the "C" and 1.27 per cent for the "L" plots, and six months later, on February 14, 1944, they were 1.24 per cent and 1.28 per cent, respectively, much above the desirable level of about one per cent which has been suggested as ideal about the time of harvest. The expected final decline of the nitrogen index after irrigation was discontinued was not realized as in the case of the plant crop (Fig. 4). The rainy weather prior to harvest might have been one cause that hindered the final drop in nitrogen content. It is a matter of interest to note here that a somewhat similar status of nitrogen levels occurred in the plant crop during the period from September 1942 to January 1943 at the crop ages of from 13½ to 17½ months (Fig. 4). This tendency of the nitrogen indices to level off and then to rise after September of the second year may be interpreted as a manifestation of the seasonal change or a combined function of the season and the age of the plant.

The crop was harvested during the period from March 1 to March 14, 1944, at the age of 21½ months. A summary of average yields submitted by F. C. Denison is presented in the following table:

TABLE IV

SUMMARY OF AVERAGE YIELDS (FIRST RATOON)

| Treatments | No. of plots | Total N/Ac. | TCPA | Y%C | TSPA |
|---|---|---|---|---|---|
| C | 7 | 160 | 145.0 | 8.5 | 12.3 |
| L | 7 | 220 | 155.0 | 8.4 | 12.8 |

(For statistical significance a minimum difference of 13.8 in TCPA and of 0.6 in TSPA are indicated requirements.)

Statistically, no significant gains were secured from the "L" treatment which received the nitrogen in accordance with the nutrient content of the plant as indicated by the leaf-punch analyses. What the result might have been if the crop had been harvested at a more advanced age when the leaf-punch nitrogen had dropped to the tentative level of approximately one per cent is an open question in view of the leaf-punch study, for the nitrogen indices of the "C" and "L" plots at the age of 20½ months were 1.24 per cent and 1.28 per cent, respectively, indicating that the crop may not have been ready for harvest at that time. The undesirably high nitrogen levels, coupled with rainy weather prior to and during harvest, appears to be associated with the poor juice quality.

For comparison, a summary of average yields of the plant crop follows:

TABLE V

SUMMARY OF AVERAGE YIELDS OF THE PLANT CROP

| Treatment | Total N/Ac. | TCPA | Y%C | TSPA |
|---|---|---|---|---|
| C | 160 | 121.4 | 12.9 | 15.6 |
| L | 220 | 123.1 | 12.5 | 15.3 |

## GENERAL DISCUSSION

Results of leaf-punch studies on the first ratoon crop of 32–8560 cane have been presented and discussed according to nitrogen index data obtained at regular and progressive intervals from the start of the crop to harvest. Some difficulties encountered in the operation of this attempted crop control and significant features obtained are presented here for discussion.

During the first six months of growth, 1.65 per cent was the maximum nitrogen index obtained, regardless of different treatments. An attempt to raise the nitrogen percentage to approximately two per cent with a total of 160 pounds of nitrogen applied up to the age of 4½ months was not successful. It indicated that the level of two per cent, which has been suggested as an adequate index under six months of age, was not necessarily essential for this first ratoon crop. The leveling off of the nitrogen indices of the "C" and "L" plots, and the rising of the indices in the "X" or no-nitrogen plots may be interpreted as being caused by either a low rate of nitrogen assimilation or a contribution of nitrogen made by the soil, or by both. Hence a total of 160 pounds of nitrogen up to the age of 4½ months in October might have been excessive. However, this attempt to raise the nitrogen level was considered adequate because in the previous plant crop the nitrogen indices of the "C" and "L" treatments were maintained almost at the level of two per cent during the first six months.

When the crop was 10½ months old in April 1943, the index of the "L" plots was 1.40 per cent, which was 0.1 per cent lower than that of the optimum treatment of the plant crop at the corresponding age. However, the consequent additional application of 60 pounds of nitrogen did not result in an increase in sugar yield at harvest. Here again the result presented difficulty in defining an optimum nitrogen level at that time.

A tangible result obtained was that the nitrogen levels during the boom stage were below the prescribed suggested limits as was the case in the previous plant crop. Thus the optimum nitrogen level for 32–8560 cane during this stage appears to be lower than the prescribed lines which have been suggested as ideal for this period of poverty adjustment.

Reference to Fig. 3 and to Fig. 4 reveals that the parallelism existing between the nitrogen levels of the plant crop and those of the first ratoon is more apparent when compared on the basis of the time (month) of sampling rather than according to the age of the crop. Thus the status of the nitrogen levels determined at the time of sampling should perhaps be given more consideration in interpreting the leaf-punch data.

In general the results of the studies revealed that the leaf-punch analyses reflected the different nitrogen levels in the active cane leaves resulting from the differences in available nitrogen supply, age and weather. However, as we have seen, the interpretation of the nitrogen indices for guidance of nitrogen fertilization for the first ratoon crop was not an easy matter. A major difference observed in the field between the plant and the first ratoon crop, aside from the authentic differences in the growth factors, was that the latter crop had more primary stalks to start with than the former. However, with leaf-punch analyses alone, the optimum nitrogen level for the early stage of growth was not definitely ascertained. Thus the operation of this crop control is still, to a large extent, a matter of speculation and may remain so until we arrive at some definite conclusion as to the exact meaning of the leaf-punch nitrogen in relation to the plant requirement. It is beyond our reach at present to define, for a crop at early ages, the specific nitrogen levels which insure an optimum sugar yield at final harvest.

We are continuing our studies on the second ratoon crop which is now well under way.

## ACKNOWLEDGMENT

The writer wishes to express his appreciation to Dr. Hance and Mr. Boyen of the Chemistry department, and to Messrs. Borden and Smith of the Agricultural department for assistance and counsel; also to Messrs. Uyehara and Yamamoto of the Chemistry department for assistance in connection with the sampling of the experiments.

## LITERATURE CITED

(1) Borden, R. J., 1941. Cane growth studies—factors which influence yields and composition of sugar cane. The Hawaiian Planters' Record, 45: 241–263.

(2) ————, 1942. A search for guidance in the nitrogen fertilization of the sugar cane crop. Part I—the plant crop. The Hawaiian Planters' Record, 46: 191–233.

(3) Clements, Harry F., 1940. Integration of climatic and physiologic factors with reference to the production of sugar cane. The Hawaiian Planters' Record, 44: 201–233.

(4) ————, and Kubota, T., 1942. Internal moisture relations of sugar cane—the selection of a moisture index. The Hawaiian Planters' Record, 46: 17–35.

(5) ————, and Moriguchi, S., 1942. Nitrogen and sugar cane—the nitrogen index and certain quantitative field aspects. The Hawaiian Planters' Record, 46: 163–190.

(6) ————, and Kubota, T., 1943. The primary index, its meaning and application to crop management with special reference to sugar cane. The Hawaiian Planters' Record, 47: 257–297.

(7) Cornelison, A. H., 1944. Vegetative differences influence the composition of sugar cane. The Hawaiian Planters' Record, 48: 125–164.

(8) Yuen, Q. H., and Hance, Francis E., 1939. Nitrogen in the cane leaf. The Hawaiian Planters' Record, 43: 163–207.

# The Vertical Distribution of Available (Exchangeable) Potassium in Oahu Soils*

By A. S. Ayres and C. K. Fujimoto

*Although a good deal is known regarding levels of available potassium in the surface layers of Oahu soils, very little is known concerning the supplies of this element at greater depths in the soil. This paper reports a study of the supplies of potassium available to relatively deep-rooted plants such as sugar cane in zones below those tested by ordinary soil-sampling techniques.*

*The level of potassium was found in some soils to decrease with depth to the bottom of the section examined. In other soils the level decreased with depth for a distance of 1½ to 2 feet, but with greater depth rose again. It was found that analysis of the surface layer of soil only gives a very incomplete picture of the quantities of potassium available to such crops as sugar cane.*

Although the levels of available potassium in Hawaiian soils have been studied extensively, such study has been confined almost wholly to the surface layers of the soils. As a consequence very little is known regarding the levels of available potassium at greater depths in the soil. Yet, with deep-rooting plants such as sugar cane, there seems little doubt that potassium at depths of several feet, if chemically available, is also positionally available.

That the roots of sugar cane penetrate well-aerated soils to considerable depths is a matter of common observation. In a quantitative study of the distribution of sugar cane roots under plantation conditions in Hawaii, Lee (8) found that nearly 20 per cent of the weight of the entire root system was to be found at depths exceeding two feet. Further evidence that soil at substantial depths may contribute to the mineral nutrition of sugar cane has been obtained by Evans (4) in Mauritius. This worker found that when chemically available minerals were present in the subsoil, they were vigorously absorbed by the deep roots. With deep-rooted varieties of sugar cane, such as Uba, Evans obtained exudates containing mineral materials from roots severed 15 feet below the surface of the soils.

Available potassium appears, from studies in other areas, to be variously distributed in the soil profile. Thus in five profiles typical of some 40 uncultivated, podzolic Scottish soils Mitchell (11) found that exchangeable potassium in two cases decreased, and in one case increased consistently to the bottom of the sections (80–130 cm.) examined. In the two remaining profiles, levels of potassium near the surface decreased with depth and then either became constant or fluctuated with greater depth. A more uniform distribution of exchangeable potassium was found by Lilleland (9) in alluvial orchard soils in California. In all but 4 of 23 soils examined to a depth of four feet by this worker potassium decreased to the bottom of the section. In the four remaining soils there was some increase in the fourth foot. Examination of a small number of soils to a depth of eight feet indicated

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little further decrease beyond the sixth to seventh foot. Study of Queensland sugar cane soils to a depth of two feet by Davidson (3) and of calcareous Arizona soils to a depth of three feet by McGeorge (10) revealed distribution patterns similar to those already noted.

No published record has been found dealing with the vertical distribution of available potassium in Hawaiian soils. Some study of the subject has been made, however, in connection with specific plantation problems, the results being contained in Experiment Station, H.S.P.A. reports. From these it is seen that Hance (7) examined the upper five feet of a profile in a sugar cane field soil at Puunene, Maui, and found that exchangeable potassium diminished from the surface of the soil to the bottom of the section. Profiles in two sugar cane field soils at Ewa, Oahu, were examined for exchangeable potassium to depths of five feet by Gow (6), who observed that potassium diminished with depth to about the two-foot level and remained constant from that point to the bottom of the section. It appears from the foregoing review that, as a rule, exchangeable potassium decreases with depth near the surface of the soil and at greater depths may continue to decrease, may remain constant, or even increase.

## Description of the Soils Examined

The soils examined are essentially clay soils and are lateritic in nature. They include alluvial, residual and colluvial types. Elevations range from about 25 feet to approximately 1,000 feet and mean annual rainfall from about 20 to 90 inches. A water table exists near the surface in the case of one of the soils sampled (No. 43–91).

The majority of the soils studied are under cultivation, being principally devoted to the production of sugar cane. Due to the low rainfall in these areas agricultural soils are generally intensively irrigated. Only one of the soils examined (No. 42–19) is representative of an unirrigated agricultural soil. The soils examined, together with pertinent data, are listed in Table I.

## Method of Sampling

A trench about six feet in length and 1½ to 2 feet in depth was dug and samples of soil shaved off one face of the trench. Following this operation borings were made in the bottom of the trench and additional samples taken to the desired depths.

In the case of the cultivated soils, which in every instance were planted either to sugar cane or to Napier grass, the trench was dug midway between and parallel to the lines. It is to be expected that samples taken in this location would differ somewhat in potassium content, particularly in the upper horizons, from those which might have been taken in the line itself, since, in the first place, it is in the line that the fertilizer and generally the irrigation water are applied and, in the second place, the concentration of roots is greatest in the line. However, there seemed little reason for selecting one site in preference to another and, since sampling between the lines was obviously the more practical method, samples were in every case obtained from this location.

Hawaiian soils, like lateritic soils in general, rarely possess the marked differentiation into horizons which is frequently made the basis for the study of soil profiles in other areas. In this connection it may be seen by reference to Table I that

## TABLE I

## DESCRIPTION OF SOILS, EXCHANGEABLE POTASSIUM AND pH VALUES

| Number | Soil | Type | Elev. (ft.) | Mean annual rainfall (in.) | Color* | Vegetation | Depth (in.) | Potassium (m.e./100) | pH |
|---|---|---|---|---|---|---|---|---|---|
| 42–17a | Nuuanu | Residual | 850 | 85 | dk-yel-Br | grass, fern (virgin) | 0–6 | .30 | 4.6 |
| 17b | | | | | " | | 6–12 | .083 | 4.7 |
| 17c | | | | | " | | 12–24 | .094 | 4.7 |
| 17d | | | | | " | | 24–36 | .14 | 4.6 |
| 42–19a | Waimanalo | Colluvial | 300 | 90 | dk-yel-Br | Sugar cane | 0–6 | .44 | 5.0 |
| 19b | | | | | mod-yel-Br | | 6–12 | .089 | 4.9 |
| 19c | | | | | " | | 12–24 | .064 | 4.9 |
| 19d | | | | | " | | 24–36 | .20 | 4.7 |
| 42–20a | Waimanalo | Colluvial | 325 | 90 | dk-yel-Br | guava, plum, ti, fern (virgin) | 0–6 | 1.02 | 5.1 |
| 20b | | | | | " | | 6–12 | .44 | 5.0 |
| 20c | | | | | " | | 12–24 | .15 | 4.9 |
| 20d | | | | | " | | 24–36 | .37 | 4.7 |
| 42–21a | Waimanalo | Colluvial | 275 | 90 | dk-yel-Br | Sugar cane | 0–6 | .92 | 5.4 |
| 21b | | | | | " | | 6–12 | .18 | 5.1 |
| 21c | | | | | " | | 12–24 | .095 | 4.9 |
| 21d | | | | | " | | 24–36 | .36 | 4.8 |
| 42–22a | Aiea | Residual | 800 | 75 | mod-Br | Fern, ohia-lehua | 0–6 | .22 | 4.5 |
| 22b | | | | | " | | 6–12 | .12 | 4.3 |
| 22c | | | | | " | | 12–24 | .062 | 4.5 |
| 22d | | | | | " | | 24–36 | .096 | 4.6 |
| 42–23a | Aiea | Residual | 350 | 40 | mod-Br | Sugar cane | 0–6 | .30 | 4.8 |
| 23b | | | | | wk to mod-Br | | 6–12 | .30 | 4.8 |
| 23c | | | | | mod-Br | | 12–24 | .17 | 4.7 |
| 23d | | | | | " | | 24–36 | .13 | 4.6 |
| 42–24a | Aiea | Residual | 50 | 35 | mod-Br | Sugar cane | 0–6 | .34 | 6.6 |
| 24b | | | | | " | | 6–12 | .20 | 6.7 |
| 24c | | | | | wk-r-Br | | 12–24 | .13 | 7.5 |
| 24d | | | | | " | | 24–36 | .18 | 7.6 |
| 42–38a | Pensacola | Residual | 200 | 40 | dk-yel-Br | grass (virgin) | 0–6 | .43 | 6.3 |
| 38b | | | | | " | | 6–12 | .18 | 6.6 |
| 38c | | | | | " | | 12–18 | .11 | 6.7 |
| 38d | | | | | lt-yel-Br | | 18–24 | .28 | 6.6 |
| 38e | | | | | " | | 24–29 | .59 | 6.6 |
| 42–40a | Tantalus | Residual | 1000 | 90 | dk-yel-Br | Koa, guava, etc. (virgin) | 0–6 | .22 | 5.5 |
| 40b | | | | | " | | 6–12 | .097 | 5.3 |
| 40c | | | | | " | | 12–18 | .053 | 5.4 |
| 40d | | | | | " | | 18–24 | .041 | 5.4 |
| 40e | | | | | " | | 24–30 | .11 | 5.4 |
| 40f | | | | | " | | 30–36 | .22 | 5.4 |
| 40g | | | | | " | | 36–42 | .45 | 5.4 |
| 40h | | | | | " | | 42–48 | .84 | 5.4 |
| 40i | | | | | " | | 48–54 | .69 | 5.5 |
| 40j | | | | | " | | 54–60 | .86 | 5.4 |
| 40k | | | | | " | | 60–66 | .73 | 5.4 |
| 40l | | | | | " | | 66–72 | .97 | 5.4 |
| 43–8a | Ewa | Alluvial | 25 | 20 | mod-Br | Sugar cane | 0–6 | .99 | 7.1 |
| 8b | | | | | " | | 6–12 | .65 | 7.2 |
| 8c | | | | | " | | 12–18 | .41 | 7.3 |
| 8d | | | | | " | | 18–24 | .36 | 7.3 |
| 8e | | | | | " | | 24–30 | .30 | 7.2 |
| 8f | | | | | " | | 30–36 | .29 | 7.2 |
| 8g | | | | | " | | 36–42 | .27 | 6.9 |
| 8h | | | | | " | | 42–48 | .27 | 6.8 |
| 8i | | | | | " | | 48–54 | .26 | 6.8 |

*** U.S.D.A. color names for soils (12).**

**Abbreviations used in designating colors:**

**Br—brown. br—brownish. mod—moderate. wk—weak. Gr—gray. r—reddish. dk—dark. str—strong. yel—yellowish. lt—light.**

**Colors determined on air-dry 20-mesh soils.**

## TABLE I (Continued)

## DESCRIPTION OF SOILS, EXCHANGEABLE POTASSIUM AND pH VALUES

| Number | Soil | Type | Elev. (ft.) | Mean annual rainfall (in.) | Color* | Vegetation | Depth (in.) | Potassium (m.e./100) | pH |
|---|---|---|---|---|---|---|---|---|---|
| 43–9a | Ewa | Alluvial | 75 | 20 | wk-Br | Sugar cane | 0–6 | .32 | 7.1 |
| 9b | | | | | " | | 6–12 | .19 | 7.1 |
| 9c | | | | | " | | 12–18 | .16 | 7.0 |
| 9d | | | | | " | | 18–24 | .15 | 6.5 |
| 9e | | | | | " | | 24–30 | .15 | 5.4 |
| 9f | | | | | " | | 30–36 | .16 | 4.8 |
| 43–10a | Ewa | Residual | 75 | 20 | dk-yel-Br | Sugar cane | 0–6 | .97 | 7.4 |
| 10b | | | | | mod-yel-Br | | 6–12 | .27 | 7.3 |
| 10c | | | | | " | | 12–18 | .20 | 7.2 |
| 10d | | | | | " | | 18–21 | .19 | 7.2 |
| 43–11a | Ewa | Alluvial | 50 | 20 | mod-Br | Sugar cane | 0–6 | .78 | 7.4 |
| 11b | | | | | " | | 6–12 | .19 | 7.2 |
| 11c | | | | | " | | 12–18 | .14 | 7.0 |
| 11d | | | | | " | | 18–24 | .15 | 6.9 |
| 11e | | | | | " | | 24–30 | .17 | 6.8 |
| 11f | | | | | " | | 30–36 | .17 | 6.8 |
| 11g | | | | | " | | 36–42 | .18 | 6.8 |
| 11h | | | | | " | | 42–48 | .18 | 6.5 |
| 43–16a | Poamoho | Residual | 700 | 45 | mod to dk-Br | Napier grass | 0–6 | .20 | 6.6 |
| 16b | | | | | " | | 6–12 | .17 | 6.7 |
| 16c | | | | | mod-Br | | 12–18 | .17 | 6.6 |
| 16d | | | | | mod to str-Br | | 18–24 | .14 | 6.6 |
| 16e | | | | | " | | 24–30 | .19 | 6.8 |
| 16f | | | | | " | | 30–36 | .22 | 6.9 |
| 16g | | | | | " | | 36–42 | .24 | 6.9 |
| 16h | | | | | " | | 42–48 | .23 | 6.8 |
| 43–33a | Poamoho | Residual | 700 | 45 | wk-r-Br | None | 0–12 | .50 | 5.4 |
| 33b | | | | | " | | 12–24 | .25 | 6.3 |
| 33c | | | | | " | | 24–36 | .27 | 6.4 |
| 43–34a | Ewa | Residual | 350 | 20 | wk-Br | cactus, grass (virgin) | 0–6 | .83 | 5.6 |
| 34b | | | | | " | | 6–12 | .27 | 6.3 |
| 34c | | | | | " | | 12–18 | .16 | 6.8 |
| 34d | | | | | " | | 18–24 | .17 | 6.7 |
| 34e | | | | | " | | 24–30 | .13 | 6.7 |
| 34f | | | | | " | | 30–36 | .12 | 6.6 |
| 34g | | | | | " | | 36–42 | .12 | 6.3 |
| 34h | | | | | " | | 42–48 | .11 | 6.3 |
| 43–36a | H.A.E.S. Manoa | Alluvial | 150 | 35 | wk to dusky-Br | Napier grass | 0–6 | .53 | 6.3 |
| 36b | | | | | " | | 6–12 | .48 | 6.4 |
| 36c | | | | | " | | 12–18 | .42 | 6.4 |
| 36d | | | | | " | | 18–24 | .41 | 6.4 |
| 36e | | | | | " | | 24–30 | .39 | 6.6 |
| 36f | | | | | " | | 30–36 | .38 | 6.6 |
| 43–43a | Makaha | Alluvial | 50 | 20 | wk-Br | Sugar cane | 0–6 | .73 | 7.0 |
| 43b | | | | | " | | 6–12 | .59 | 6.9 |
| 43c | | | | | " | | 12–18 | .31 | 7.0 |
| 43d | | | | | pale to wk-Br | | 18–24 | .31 | 7.0 |
| 43e | | | | | " | | 24–30 | .29 | 7.5 |
| 43f | | | | | " | | 30.36 | .12 | 7.6 |
| 43g | | | | | " | | 36–42 | .075 | 7.7 |
| 43h | | | | | " | | 42–48 | .073 | 7.7 |

* U.S.D.A. color names for soils (12).

Abbreviations used in designating colors:

Br—brown. br—brownish. mod—moderate. wk—weak. Gr—gray. r—reddish. dk—dark. str—strong. yel—yellowish. lt—light.

Colors determined on air-dry 20-mesh soils.

## TABLE I (Continued)

## DESCRIPTION OF SOILS, EXCHANGEABLE POTASSIUM AND pH VALUES

| Number | Soil | Type | Elev. (ft.) | Mean annual rainfall (in.) | Color* | Vegetation | Depth (in.) | Potassium (m.e./100) | pH |
|---|---|---|---|---|---|---|---|---|---|
| 43–44a | Waianae | Alluvial | 50 | 20 | wk-Br | Sugar cane | 0–6 | 1.06 | 7.5 |
| 44b | | | | | pale to wk-Br | | 6–12 | .62 | 7.4 |
| 44c | | | | | " | | 12–18 | .23 | 7.4 |
| 44d | | | | | " | | 18–24 | .17 | 7.4 |
| 44e | | | | | " | | 24–30 | .15 | 7.4 |
| 44f | | | | | " | | 30–36 | .14 | 7.3 |
| 44g | | | | | " | | 36–42 | .14 | 7.3 |
| 44h | | | | | " | | 42–48 | .11 | 7.8 |
| 43–45a | Lualualei | Alluvial | 75 | 20 | wk-Br | Sugar cane | 0–6 | 1.38 | 7.8 |
| 45b | | | | | br-Gr to wk-Br | | 6–12 | .95 | 7.7 |
| 45c | | | | | " | | 12–18 | .48 | 7.5 |
| 45d | | | | | wk to mod-Br | | 18–24 | .29 | 7.5 |
| 45e | | | | | " | | 24–30 | .29 | 7.2 |
| 45f | | | | | pale to wk-Br | | 30–36 | .24 | 7.3 |
| 45g | | | | | " | | 36–42 | .19 | 7.3 |
| 43–48a | Kunia | Residual | 200 | 20 | wk-r to mod-r-Br | Sugar cane | 0–6 | .19 | 6.5 |
| 48b | | | | | " | | 6–12 | .13 | 6.7 |
| 48c | | | | | " | | 12–18 | .088 | 7.0 |
| 48d | | | | | " | | 18–24 | .095 | 7.1 |
| 48e | | | | | " | | 24–30 | .092 | 7.0 |
| 48f | | | | | " | | 30–36 | .094 | 7.0 |
| 48g | | | | | " | | 36–42 | .098 | 6.9 |
| 48h | | | | | " | | 42–48 | .11 | 6.9 |
| 43–49a | Waipahu | Residual | 250 | 25 | wk-r-Br | Sugar cane | 0–6 | .094 | 6.1 |
| 49b | | | | | " | | 6–12 | .079 | 6.1 |
| 49c | | | | | " | | 12–18 | .075 | 6.4 |
| 49d | | | | | " | | 18–24 | .085 | 6.4 |
| 49e | | | | | " | | 24–30 | .11 | 6.4 |
| 49f | | | | | " | | 30–36 | .13 | 6.4 |
| 49g | | | | | " | | 36–42 | .094 | 6.4 |
| 49h | | | | | " | | 42–48 | .095 | 6.4 |
| 49i | | | | | " | | 48–54 | .095 | 6.4 |
| 49j | | | | | " | | 54–60 | .071 | 6.4 |
| 49k | | | | | " | | 60–66 | .065 | 6.5 |
| 49l | | | | | " | | 66–72 | .047 | 6.6 |
| 49m | | | | | " | | 72–78 | .037 | 6.6 |
| 49n | | | | | " | | 78–84 | .037 | 6.6 |
| 43–50a | Waipahu | Residual | 400 | 30 | wk-r-Br | Sugar cane | 0–6 | .43 | 6.3 |
| 50b | | | | | " | | 6–12 | .15 | 6.2 |
| 50c | | | | | wk-r mod to r-Br | | 12–18 | .091 | 6.3 |
| 50d | | | | | " | | 18–24 | .083 | 6.4 |
| 50e | | | | | " | | 24–30 | .076 | 6.5 |
| 50f | | | | | " | | 30–36 | .054 | 6.5 |
| 50g | | | | | " | | 36–42 | .040 | 6.4 |
| 50h | | | | | " | | 42–48 | .034 | 6.4 |
| 43–66a | Waialua | Alluvial | 20 | 30 | wk to mod-Br | Sugar cane | 0–6 | 1.09 | 6.6 |
| 66b | | | | | " | | 6–12 | .87 | 6.7 |
| 66c | | | | | " | | 12–18 | .45 | 6.5 |
| 66d | | | | | pale to wk-Br | | 18–24 | .26 | 6.5 |
| 66e | | | | | " | | 24–30 | .22 | 6.4 |
| 66f | | | | | " | | 30–36 | .21 | 6.4 |
| 66g | | | | | " | | 36–42 | .20 | 6.3 |
| 66h | | | | | " | | 42–48 | .21 | 6.3 |

* U.S.D.A. color names for soils (12).

Abbreviations used in designating colors:

Br—brown. br—brownish. mod—moderate. wk—weak. Gr—gray. r—reddish. dk—dark. str—strong. yel—yellowish. lt—light.

Colors determined on air-dry 20-mesh soils.

## TABLE I (Continued)

## DESCRIPTION OF SOILS, EXCHANGEABLE POTASSIUM AND pH VALUES

| Number | Soil | Type | Elev. (ft.) | Mean annual rainfall (in.) | Color* | Vegetation | Depth (in.) | Potassium (m.e./100) | pH |
|---|---|---|---|---|---|---|---|---|---|
| 43–67a | Waialua | Alluvial | 25 | 30 | pale to wk-Br | Sugar cane | 0–6 | 2.27 | 6.4 |
| 67b | | | | | " | | 6–12 | 1.90 | 6.3 |
| 67c | | | | | wk-Br | | 12–18 | 1.16 | 6.3 |
| 67d | | | | | " | | 18–24 | .61 | 6.4 |
| 67e | | | | | wk to mod-Br | | 24–30 | .75 | 6.4 |
| 67f | | | | | " | | 30–36 | .83 | 6.3 |
| 43–68a | Waialua | Residual | 175 | 30 | wk to mod-Br | Sugar cane | 0–6 | .62 | 6.5 |
| 68b | | | | | " | | 6–12 | .47 | 6.6 |
| 68c | | | | | " | | 12–18 | .41 | 6.6 |
| 68d | | | | | " | | 18–24 | .35 | 6.6 |
| 68e | | | | | wk-r-Br | | 24–30 | .37 | 6.6 |
| 68f | | | | | " | | 30–36 | .42 | 6.5 |
| 68g | | | | | " | | 36–42 | .51 | 6.4 |
| 68h | | | | | " | | 42–48 | .70 | 6.5 |
| 43–69a | Waialua | Residual | 350 | 45 | wk-r-Br | Sugar cane | 0–6 | .65 | 5.8 |
| 69b | | | | | " | | 6–12 | .36 | 6.1 |
| 69c | | | | | wk to mod r-Br | | 12–18 | .23 | 6.2 |
| 69d | | | | | " | | 18–24 | .20 | 6.2 |
| 69e | | | | | " | | 24–30 | .17 | 6.2 |
| 69f | | | | | " | | 30–36 | .17 | 6.2 |
| 69g | | | | | " | | 36–42 | .19 | 6.2 |
| 69h | | | | | " | | 42–48 | .18 | 6.2 |
| 43–70a | Waialua | Residual | 400 | 35 | wk-r-Br | Sugar cane | 0–6 | .40 | 4.0 |
| 70b | | | | | " | | 6–12 | .35 | 4.2 |
| 70c | | | | | wk to mod-r-Br | | 12–18 | .27 | 3.9 |
| 70d | | | | | " | | 18–24 | .23 | 4.6 |
| 70e | | | | | " | | 24–30 | .23 | 4.7 |
| 70f | | | | | " | | 30–36 | .24 | 4.7 |
| 70g | | | | | " | | 36–42 | .25 | 4.7 |
| 70h | | | | | " | | 42–48 | .26 | 4.7 |
| 43–90a | Kahuku | Alluvial | 25 | 35 | br-Gr to wk-r-Br | Sugar cane | 0–6 | .33 | 5.0 |
| 90b | | | | | " | | 6–12 | .19 | 5.0 |
| 90c | | | | | " | | 12–18 | .15 | 4.9 |
| 90d | | | | | " | | 18–24 | .11 | 5.0 |
| 90e | | | | | " | | 24–30 | .11 | 4.9 |
| 90f | | | | | " | | 30–36 | .10 | 4.9 |
| 90g | | | | | " | | 36–42 | .090 | 4.9 |
| 90h | | | | | " | | 42–48 | .098 | 4.8 |
| 43–91a | Kahuku | Alluvial | 25 | 50 | br-Gr to wk-Br | Sugar cane | 0–6 | .22 | 6.1 |
| 91b | | | | | " | | 6–12 | .22 | 6.3 |
| 91c | | | | | " | | 12–18 | .12 | 6.3 |
| 91d | | | | | " | | 18–24 | .048 | 6.1 |
| 91e | | | | | " | | 24–30 | .042 | 5.7 |
| 91f | | | | | " | | 30–36 | .039 | 5.1 |
| 91g | | | | | " | | 36–42 | .072 | 4.0 |
| 91h | | | | | " | | 42–48 | .078 | 4.1 |
| 44–17a | Waialua | Alluvial | 25 | 30 | br-Gr to wk-Br | Sugar cane | 0–6 | 2.31 | 6.8 |
| 17b | | | | | " | | 6–12 | 2.35 | 6.9 |
| 17c | | | | | wk-Br | | 12–18 | 1.38 | 6.9 |
| 17d | | | | | " | | 18–24 | 1.17 | 7.0 |
| 17e | | | | | " | | 24–30 | 1.06 | 6.8 |
| 17f | | | | | " | | 30–36 | 1.30 | 6.9 |
| 17g | | | | | " | | 36–42 | 1.32 | 6.8 |
| 17h | | | | | " | | 42–48 | 1.29 | 6.8 |

* U.S.D.A. color names for soils (12).
Abbreviations used in designating colors:
Br—brown. br—brownish. mod—moderate. wk—weak. Gr—gray. r—reddish. dk—dark. str—strong. yel—yellowish. lt—light.
Colors determined on air-dry 20-mesh soils.

changes in color in the profile, where they exist at all, are moderate. Profile samples were accordingly taken on an arbitrary basis. During the first part of the study samples representing 6- and 12-inch horizons were obtained. Later, the sampling procedure was so modified that each sample represented a 6-inch horizon only.

The soils were initially sampled to a depth of three feet, but sampling was subsequently extended to include the fourth foot as well. In a few instances samples were obtained from depths somewhat greater than four feet. Some shallow soils were encountered and in these the depth of sampling was determined by the depth of the soil. No attempt was made to sample the entire soil profile (*i.e.*, from the surface of the soil down to the underlying unweathered material), where the depth of the profile exceeded four feet. The depths to which all samples were taken are indicated in Table I.

## METHODS OF ANALYSIS

Exchangeable potassium was chosen as the measure of available potassium. This fraction of the total soil potassium is generally considered to include all of the soil potassium available to plants at a particular moment. It is considerably greater in amount than the locally more familiar RCM* potassium, at least in Hawaiian soils.

Exchangeable potassium was extracted from the soils with normal ammonium acetate adjusted to pH 6.8. Potassium in the extracts was determined by the cobal tinitrite method of Volk and Truog (13).

pH values were measured with the glass electrode.

## EXPERIMENTAL RESULTS

The levels of exchangeable potassium in the profiles, together with the corresponding pH values, are presented in tabular form in Table. I. The former results are also depicted graphically in a series of bar-diagrams. In these diagrams each horizon in the profile is represented by a bar, the height of which indicates the level of potassium in the particular horizon. Levels of potassium are indicated in two ways: (*a*) in the conventional terms of milli-equivalents per 100 grams of oven-dry soil, and (*b*) in the more familiar terms of pounds $K_2O$ per acre six inches of oven-dry soil. The latter values are to be found immediately above the bars.

### *Distribution of Available Potassium in the Soil:*

Potassium appears to be distributed in the soils examined according to essentially three patterns. In the first of these patterns, exemplified by Figs. 1 to 8, potassium is at a maximum in the 0-to-6-inch horizon, except in the fields plowed a short time prior to sampling, and decreases with depth to the bottom of the section sampled. The decrease in level of potassium with depth may be a relatively gradual one, as in Figs. 2 and 5, or it may be very abrupt as, for example, in Figs. 3 and 8. In either case the diminution in the level of potassium is much more rapid in the upper portion of the section than in the lower. The lack of differentiation between the 0-to-6- and 6-to-12-inch horizons in soil 42–23 (Fig. 1) presumably resulted from the fact that the field had been plowed and otherwise cultivated a

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*** Rapid chemical methods of analysis, Experiment Station, H.S.P.A., Honolulu.**

short time prior to sampling and hence the surface foot of soil had been rendered more or less uniform. The distribution of potassium in the Puunene soil examined by Hance (7) corresponds to the first pattern.

The second of the three distribution patterns is illustrated in Figs. 9–13. In this pattern, which may be regarded as a modification of the first type, potassium decreases with depth, but only to 18–24 inches. Below this point the level of potassium shows practically no change. This distribution pattern, which is present in some of the Ewa soils examined in this study, is also the pattern found by Gow (6) in his earlier examination of soils from this plantation.

In the first and second types of profiles, potassium is from 1½ to 13 times greater in amount in the surface six inches of soil than in the corresponding horizons containing the lowest levels of potassium.

Distribution of potassium in the soil profile according to the third pattern is indicated in Figs. 14 to 30. In these profiles potassium decreases downward from the surface to a point usually within the second foot, but with greater depth rises again. The increase above the minimum value is very slight in the cases of two or three of the soils. In the remainder of the soils of this class, however, the rise is marked, values sometimes reaching many times the minimal value. In three of the soils, levels of potassium at depths ranging from 2½ to 6 feet were even greater than those in the corresponding 0-to-6-inch layers of the soils. The lack of differentiation in potassium content between the 0-to-6- and 6-to-12-inch horizons in the case of soil 43–91 (Fig. 30) is explainable on the basis that the field was a very young plant field and hence mixing of the surface foot of soil had occurred not long before the soil was sampled.

Levels of potassium in the Tantalus profile (Fig. 21) change so irregularly with depth beyond the three-foot level, and this lack of uniformity is so unusual in the present study that a word of explanation may be in order. The Tantalus soil is a young soil which has been formed in place from volcanic ash and is not deeply weathered. No well-defined line of demarkation existed between the soil and the parent material at the point where the sample was taken, but from a depth of about three feet down to the bottom of the section the soil contained varying quantities of weathered ash and hence samples representing the deeper horizons contained disproportionate amounts of the two materials. It seems probable that this fact accounts for the observed irregularities in the potassium content of the section.

The quantities of potassium found in the alluvial Waialua soil (Fig. 26) were unusually high. In view of this fact and the common observation that alluvial soils of this type are frequently very non-uniform with respect to available mineral content, it was decided for the purpose of comparison to obtain samples from a second vertical section in another part of the same field. The levels of potassium in the horizons of the second profile section are illustrated in Fig. 28. Although the potassium contents of the 0-to-6-inch layers of the two sections are almost identical, in all horizons below this level potassium is even higher in the second section than in the first. The relationships between the potassium contents of the 0-to-6- and 6-to-12-inch horizons mean little in this case since the field had been plowed a short time before the samples were taken. Potassium is distributed in both sections from this field according to the third pattern, that is, potassium decreases to a minimum around the second foot and rises with greater depth.

Soil No. 43–49 (Fig. 31) does not appear to conform to any of the three distribution patterns. Thus there is practically no decrease in potassium with depth through the first foot or two of soil and a maximum occurs in the 30-to-36-inch horizon. This is followed by a gradual decrease. The low levels of potassium in all horizons of this profile tend, however, to magnify differences which in a soil better supplied with potassium might be ignored.

*Total Quantities of Available Potassium in the Soils:*

If the quantities of potassium present in the various soil horizons are added together some idea may be gained of the total amounts of potassium to which, to certain depths, the plants have access. The range in the levels of available potassium to depths of three and four feet are shown in Table II.

TABLE II

AVAILABLE (EXCHANGEABLE) POTASSIUM IN SOILS IN POUNDS $K_2O$ PER ACRE

| Soil zone | Virgin soils | Agric. soils |
|---|---|---|
| 0 to 3 feet | 370–1,485 | 335–5,635 |
| 0 to 4 feet | ........ | 450–7,180 |

These ranges appear very large in view of the fact that the identical crop, namely, sugar cane, is produced on all but two of the agricultural soils represented in the table, and hence the demand upon the soils for potassium is similar.

*Effect of Cropping on the Distribution of Available Potassium in the Soil Profile:*

At Ewa, Aiea, Waimanalo and Poamoho profile samples were obtained from soils in uncropped as well as cropped areas. From these it should be possible to obtain some indication of the effect of agricultural practices upon the vertical distribution of potassium in the soil. Considering first the residual, virgin Ewa soil 43–34 (Fig. 10), it will be seen that the distribution of potassium is not dissimilar to that in some of the cropped soils of this plantation, particularly is it not unlike, in major respects, that in the residual cropped soil No. 43–10 (Fig. 3) with which it can most justifiably be compared. At Waimanalo, also the virgin and the two cropped soils sampled possessed very similar distribution patterns (Figs. 15–17) although the quantities of potassium in the soils were different. Similar results were obtained in the Aiea soils. At Poamoho, on the other hand, the distribution of potassium in soil cropped to Napier grass differed sharply from that in the soil of an adjacent uncropped area, as may be seen by a comparison of Figs. 23 and 24. It will be noted that the decrease in potassium with depth in the uncropped soil is pronounced, whereas that in the corresponding cropped soil is relatively very slight, potassium in the latter decreasing only from 120 pounds $K_2O$ per acre in the 0-to-6-inch horizon to a minimum of 85 pounds in the 18-to-24-inch horizon. The reason cropping has apparently affected the distribution of potassium in the Poamoho soils and not in the other soils which have been considered will become more apparent in the following section.

## DISCUSSION

Although too little is known regarding the factors determining the distribution of exchangeable potassium in the soil to explain completely the observed results, yet certain processes may be pointed out, the effects of which appear to be in accord with the facts. Let us consider first an uncropped soil upon which some sort of vegetation is growing. The roots of the plants will absorb potassium from the soil to depths depending upon the type of plant and other factors, and from the roots most of the potassium will be transported to the aerial portions of the plant. Much of this potassium, either through the death of the plant or through the sloughing of dead tissues, will subsequently be deposited upon the surface of the soil, whence leaching will gradually carry it downward. In this manner vegetation tends to maintain a diminishing downward potassium gradient in the upper horizons of the soil.

The situation differs in the case of sugar cane field soils in that part of the potassium in the above-ground portions of the plant is removed from the field at harvest. The equivalent of this potassium may or may not be returned to the soil through fertilization. The substantial nature of the movement of potassium from the root zone of sugar cane field soils to the surface may be seen from the following: It was found by the writer (1) that, in the course of the production of a 100-ton crop of sugar cane, in the neighborhood of 550 pounds of $K_2O$ per acre were transferred from the soil to the aerial portions of the plant. Of this amount of potassium approximately 250 pounds were present in the millable cane and were removed from the field at harvest. The remainder of the potassium, *i.e.*, that contained in the tops, dead leaves and dead cane amounted to 300 pounds* and was returned to the surface of the soil through the processes of burning, leaching and microorganic decomposition. In addition to potassium thus brought to the soil surface during each crop, further quantities of potassium, as has been noted, are frequently applied to the soil as fertilizer. The continuous operation of this "cycle" appears to account for the observed diminishing potassium gradients in the upper horizons of the sugar cane soils studied.

It was pointed out in the preceding section that potassium decreased only slightly with depth in the Napier grass soil at Poamoho (Fig. 23). The same is true also of a University Farm, Manoa soil (Fig. 4) which is similarly devoted to the continuous production of Napier grass. The distribution patterns for potassium in these soils thus contrast strikingly with those in the virgin and sugar cane soils. The reason for this difference appears to be as follows: The two factors to which have been ascribed the observed diminishing potassium gradients in the upper horizons of the virgin and sugar cane soils are almost wholly lacking in the case of the Napier grass soils. In the first place, under Napier grass culture as practiced in these areas, practically no plant residues are returned to the surface of the soil, the crops being harvested at the age of about four months and while nearly all of the leaves are still green and attached to the stem. In the second place no potassium has been applied to the Poamoho soil as fertilizer in recent years and only 100 pounds of $K_2O$ per acre to the Manoa soil since 1939. As a result there has been little or no building up of potassium in the surface layers of these soils. It seems logical to conclude, therefore, that the nature of the crop and the associated cultural practices are responsible for the low potassium gradients in the Napier grass soils. The same factors appear to account for the fact that the distribution of potassium in the Poamoho soil was much more affected by cropping than was the case in the sugar cane soils.

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* Where sugar cane is harvested by machines, proportionately smaller quantities of the potassium taken up by the crop are returned to the soil.

It was shown by Fireman and Bodman (5) and by the writer (2) that when non-vegetative soils are leached with distilled water a potassium gradient *increasing* with depth is established. The effects of vegetation, in the absence of appreciable leaching, and of leaching, in the absence of vegetation, are thus to produce potassium gradients which are opposite in direction. Since potassium in the soils studied decreases with depth in the soil, it must be concluded that under the conditions of rainfall and irrigation encountered in this study the direction of the gradient in the soil is determined by the action of the vegetation rather than of leaching.

## SIGNIFICANCE OF THE RESULTS WITH RESPECT TO SOIL SAMPLING

If the chemical and positional availabilities of exchangeable potassium to depths of several feet be assumed, then it is apparent that the ordinary techniques of soil sampling, involving only the surface layer of the soil, result in a very incomplete picture of the quantities of potassium at the disposal of the crop. Manifestly, it is not feasible in ordinary soil-testing work to attempt the laborious sampling methods employed in this study of the soil profile. It would seem well to bear in mind, however, the limitations of surface sampling and to weigh the results obtained therefrom accordingly.

## SUMMARY

A study was made of the distribution of exchangeable potassium in Oahu soil profiles. The results may be summarized as follows:

Potassium in the profiles was found to be distributed according to one of the three following patterns:

1. Potassium decreased with depth to the bottom of the section of the profile examined.

2. Potassium decreased downward to a point within the section and thereafter remained constant.

3. Potassium decreased with depth to about 1½ to 2 feet and increased with greater depth.

The total quantities of exchangeable potassium present in the 0-to-3-foot zone ranged from 335 to 5,635 pounds, and in the 0-to-4-foot zone from 450 to 7,180 pounds of $K_2O$ per acre, respectively.

It is apparent that sampling techniques which involve only the surface layers of the soil result in very incomplete pictures of the quantities of potassium available to deep-rooted plants such as sugar cane.

The production of sugar cane does not appear to have substantially altered the natural vertical distribution pattern of exchangeable potassium in the soil.

## LITERATURE CITED

(1) Ayres, A. S., 1930. Cane growth studies at Waipio Substation. The Hawaiian Planters' Record, 34: 445–460.

(2) ———, 1944. Susceptibility of exchangeable potassium in Hawaiian soils to loss by leaching. The Hawaiian Planters' Record, 48: 83–92.

(3) Davidson, J. C. B., 1935. The distribution of available mineral plant foods. Proc. Queensland Soc. of Sugar Cane Tech., 6: 40–42.

(4) Evans, H., 1937. The root system of the sugar-cane, Pt. IV. Emp. Jr. Exp. Agr., 5: 112-124.

(5) Fireman, Milton, and Bodman, G. B., 1939. The effect of saline irrigation water upon the permeability and base status of soils. Soil Sci. Soc. Proc., 4: 71–77.
(6) Gow, P. L., 1932. Report to the chemist on the effect of fertilization with potassium upon the concentrations of exchangeable potassium in Ewa soil profiles.
(7) Hance, Francis E., 1932. Report to H. C. & S. Co., Ltd., Puunene, Maui, on studies of potassium in soils and irrigation water.
(8) Lee, H. A., 1926. Proc. 46th Annual Meeting, Hawaiian Sugar Planters' Ass'n.: 252–254.
(9) Lilleland, Omund, 1932. The distribution of potassium in deciduous orchard soils in California. Soil Science, 34: 11–18.
(10) McGeorge, W. T., 1933. Potassium in calcareous soils. Ariz. Agr. Expt. Sta. Tech. Bul. 50, 42 pp. illus.
(11) Mitchell, R. L., 1937. Base exchange equilibria in soil profiles. Journ. Agr. Sci., 27: 557–568.
(12) Rice, T. D., Nickerson, Dorothy, O'Neal, A. M., and Thorp, James, 1941. Preliminary color standards and color names for soils. U.S.D.A. Misc. Pub. No. 425.
(13) Volk, N. J., and Truog, E., 1934. A rapid chemical method for determining the readily available potash of soils. Journ. Amer. Soc. Agron., 26: 537–546.

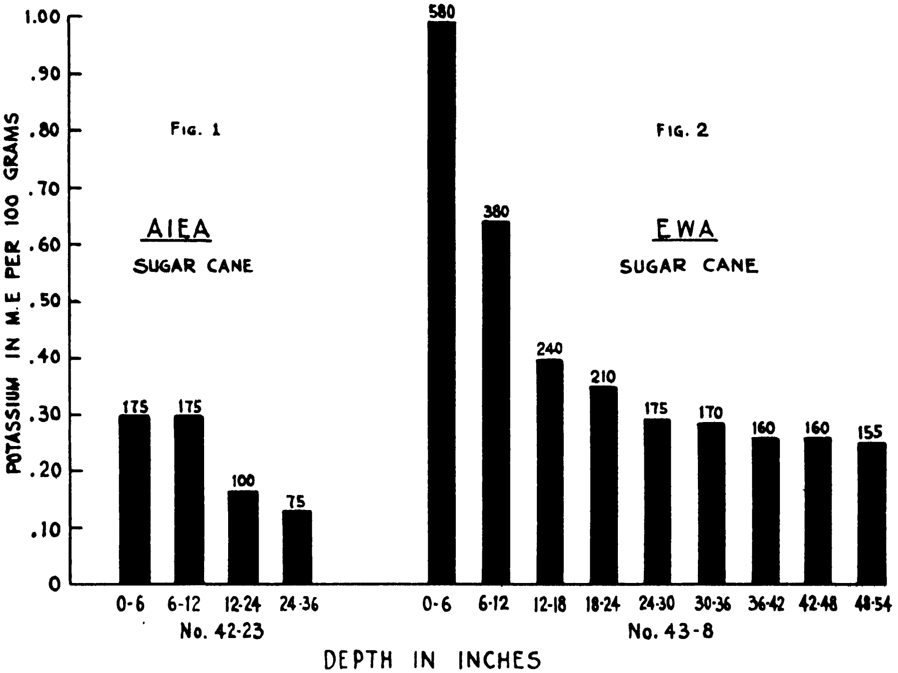
Fig. 1
AIEA
SUGAR CANE
Fig. 2
EWA
SUGAR CANE
POTASSIUM IN M.E PER 100 GRAMS
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
175
175
100
75
580
380
240
210
175
170
160
160
155
0-6
6-12
12-24
24-36
No. 42-23
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
48-54
No. 43-8
DEPTH IN INCHES

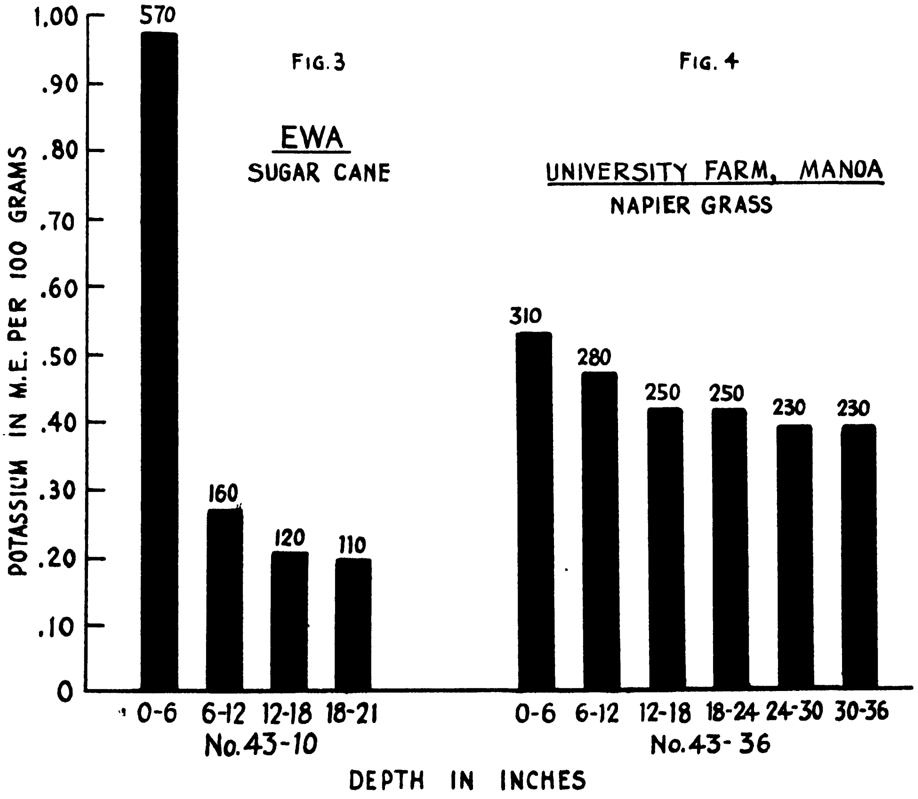
Fig. 3
EWA
SUGAR CANE
Fig. 4
UNIVERSITY FARM, MANOA
NAPIER GRASS
POTASSIUM IN M.E. PER 100 GRAMS
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
570
160
120
110
310
280
250
250
230
230
0-6
6-12
12-18
18-21
No. 43-10
0-6
6-12
12-18
18-24
24-30
30-36
No. 43-36
DEPTH IN INCHES

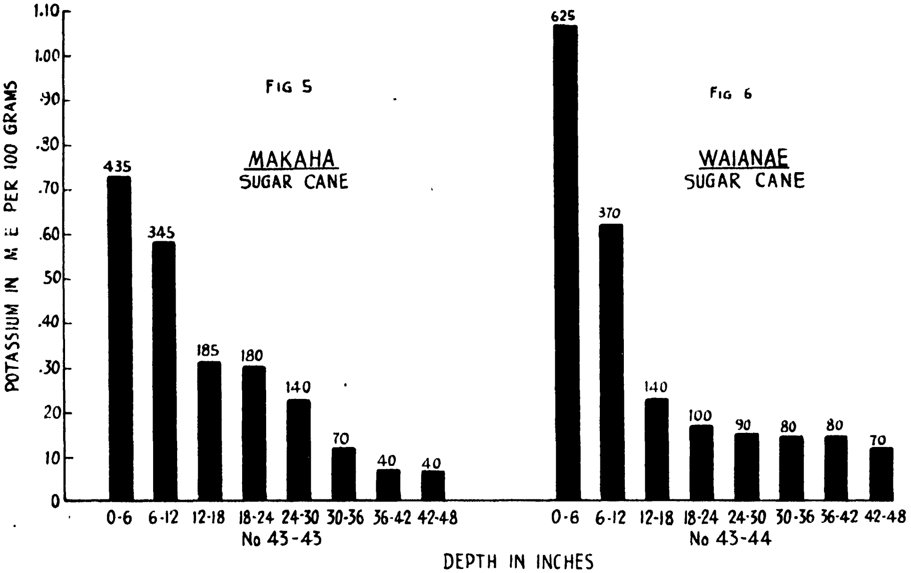
FIG 5
MAKAHA
SUGAR CANE
FIG 6
WAIANAE
SUGAR CANE
POTASSIUM IN M E PER 100 GRAMS
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
435
345
185
180
140
70
40
40
625
370
140
100
90
80
80
70
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No 43-43
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No 43-44
DEPTH IN INCHES

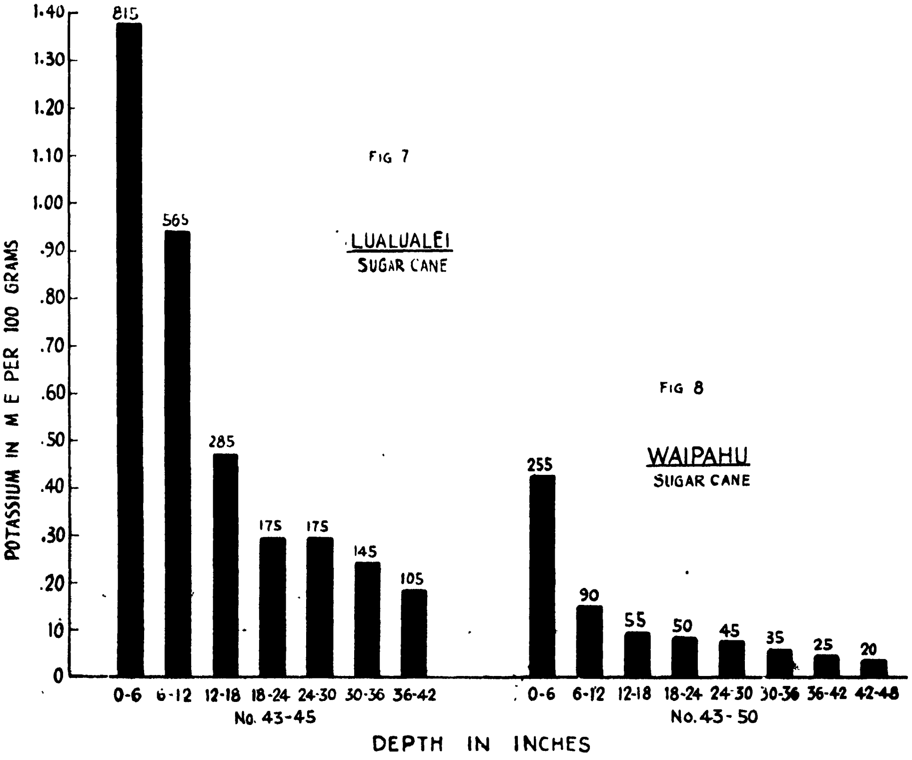
FIG 7
LUALUALEI
SUGAR CANE
FIG 8
WAIPAHU
SUGAR CANE
POTASSIUM IN M E PER 100 GRAMS
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
815
565
285
175
175
145
105
255
90
55
50
45
35
25
20
0-6
6-12
12-18
18-24
24-30
30-36
36-42
No. 43-45
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No. 43-50
DEPTH IN INCHES

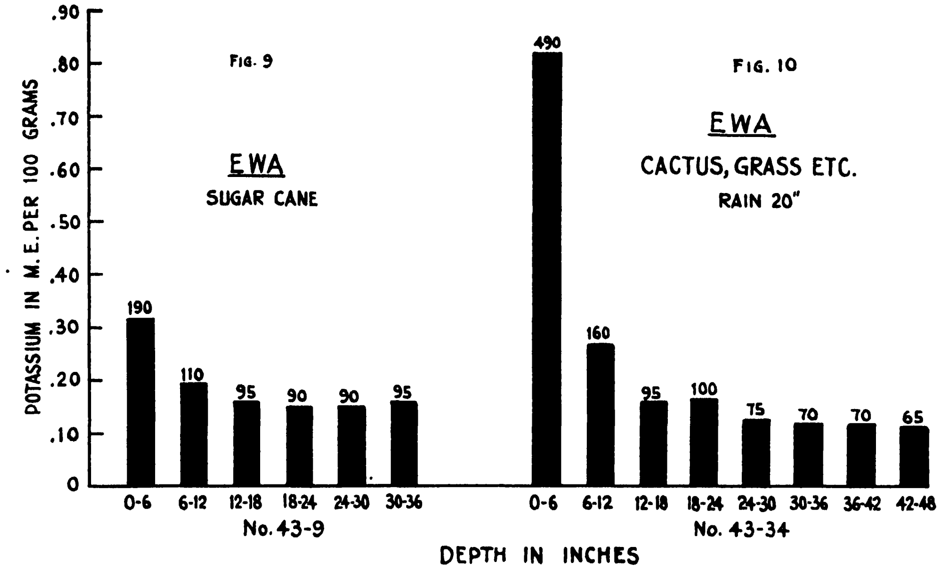
FIG. 9
EWA
SUGAR CANE
FIG. 10
EWA
CACTUS, GRASS ETC.
RAIN 20"
POTASSIUM IN M.E. PER 100 GRAMS
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
190
110
95
90
90
95
490
160
95
100
75
70
70
65
0-6
6-12
12-18
18-24
24-30
30-36
No. 43-9
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No. 43-34
DEPTH IN INCHES

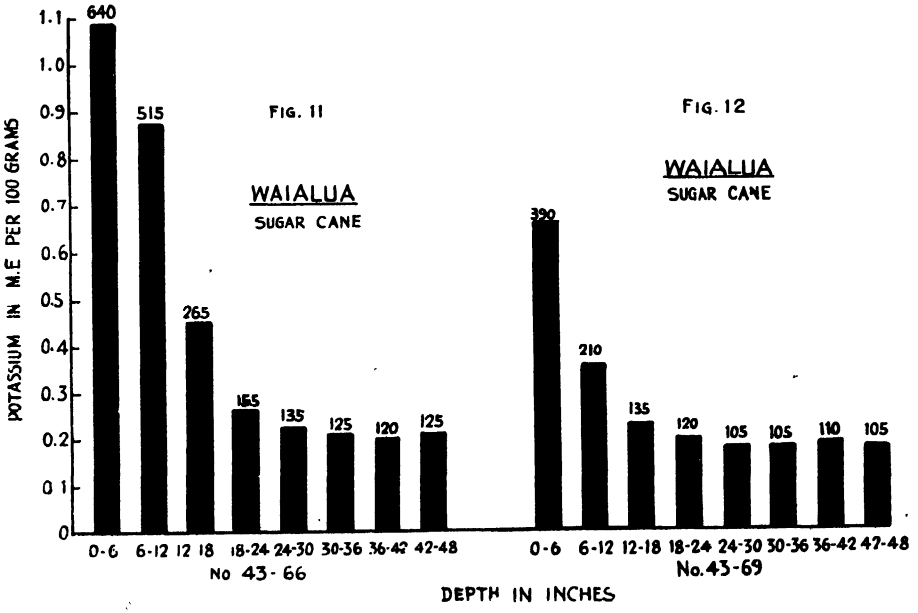
FIG. 11
WAIALUA
SUGAR CANE
FIG. 12
WAIALUA
SUGAR CANE
POTASSIUM IN M.E PER 100 GRAMS
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
640
515
265
165
135
125
120
125
390
210
135
120
105
105
110
105
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No 43-66
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No. 43-69
DEPTH IN INCHES

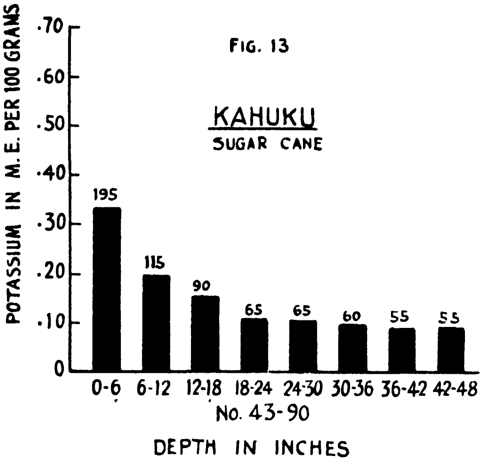
FIG. 13
KAHUKU
SUGAR CANE
POTASSIUM IN M.E. PER 100 GRAMS
.70
.60
.50
.40
.30
.20
.10
0
195
115
90
65
65
60
55
55
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No. 43-90
DEPTH IN INCHES

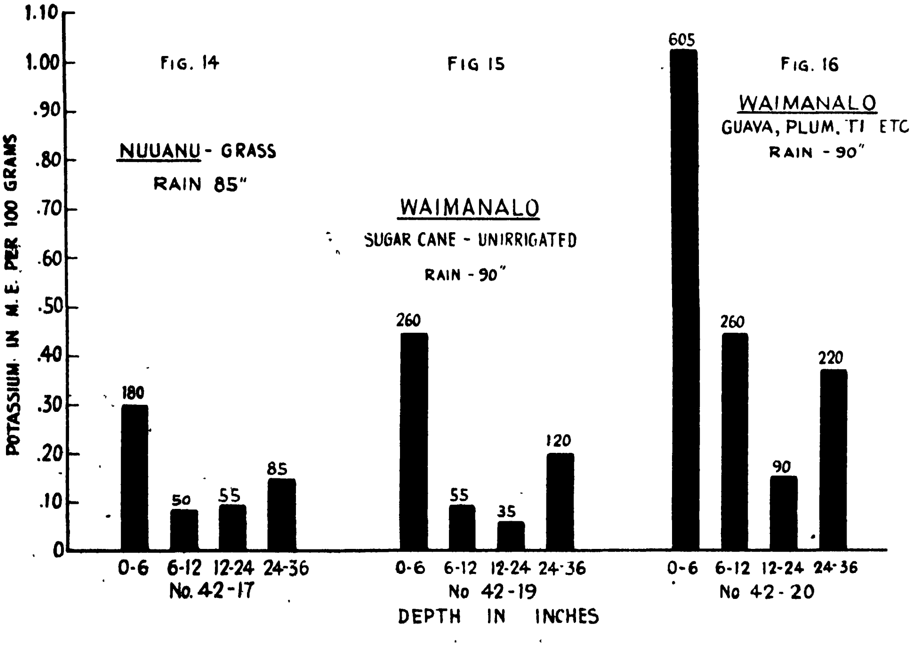
FIG. 14
FIG 15
FIG. 16
POTASSIUM IN M.E. PER 100 GRAMS
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
NUUANU - GRASS
RAIN 85"
180
50
55
85
0-6
6-12
12-24
24-36
No. 42-17
WAIMANALO
SUGAR CANE - UNIRRIGATED
RAIN - 90"
260
55
35
120
0-6
6-12
12-24
24-36
No 42-19
WAIMANALO
GUAVA, PLUM, TI ETC
RAIN - 90"
605
260
90
220
0-6
6-12
12-24
24-36
No 42-20
DEPTH IN INCHES

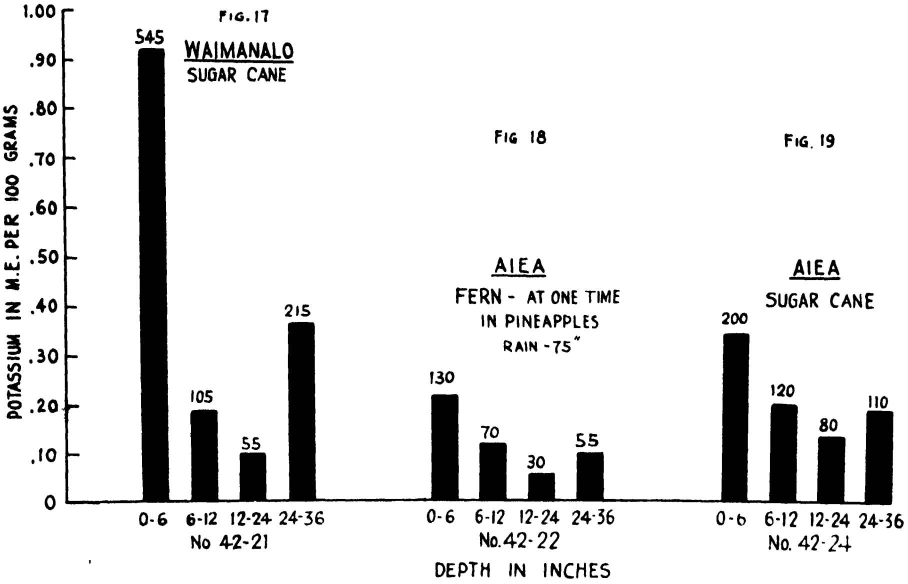

FIG. 17

FIG 18

FIG. 19

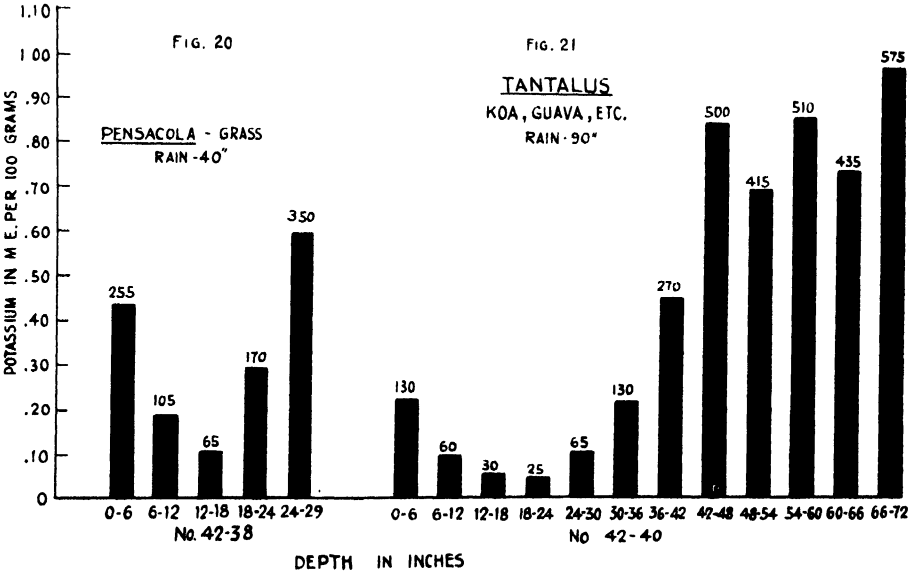

FIG. 20

FIG. 21

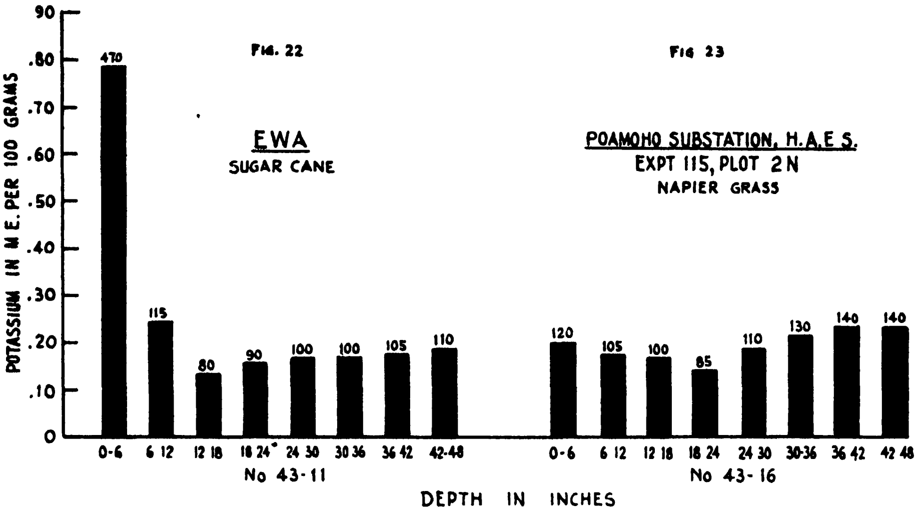

FIG. 22

FIG. 23

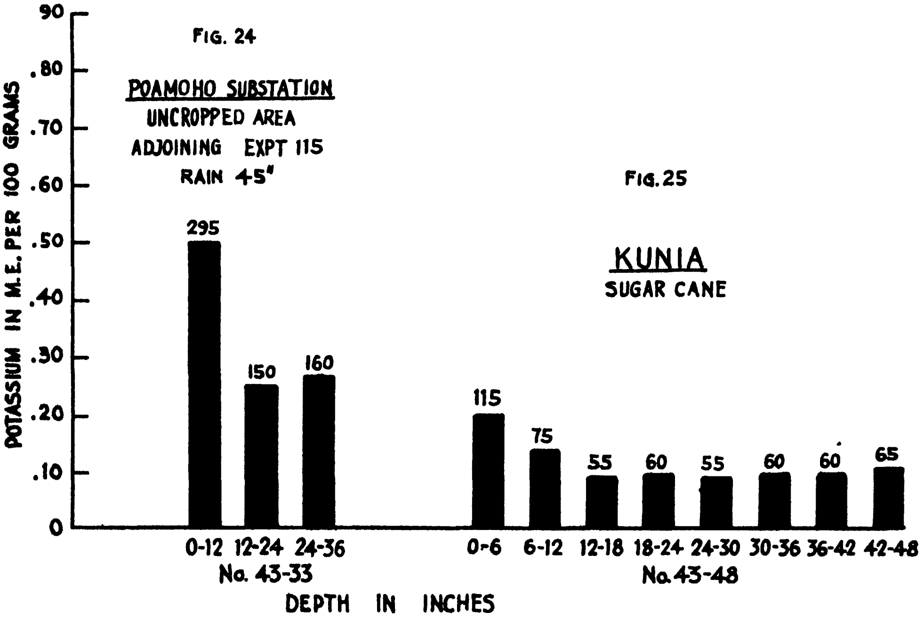

FIG. 24

FIG. 25

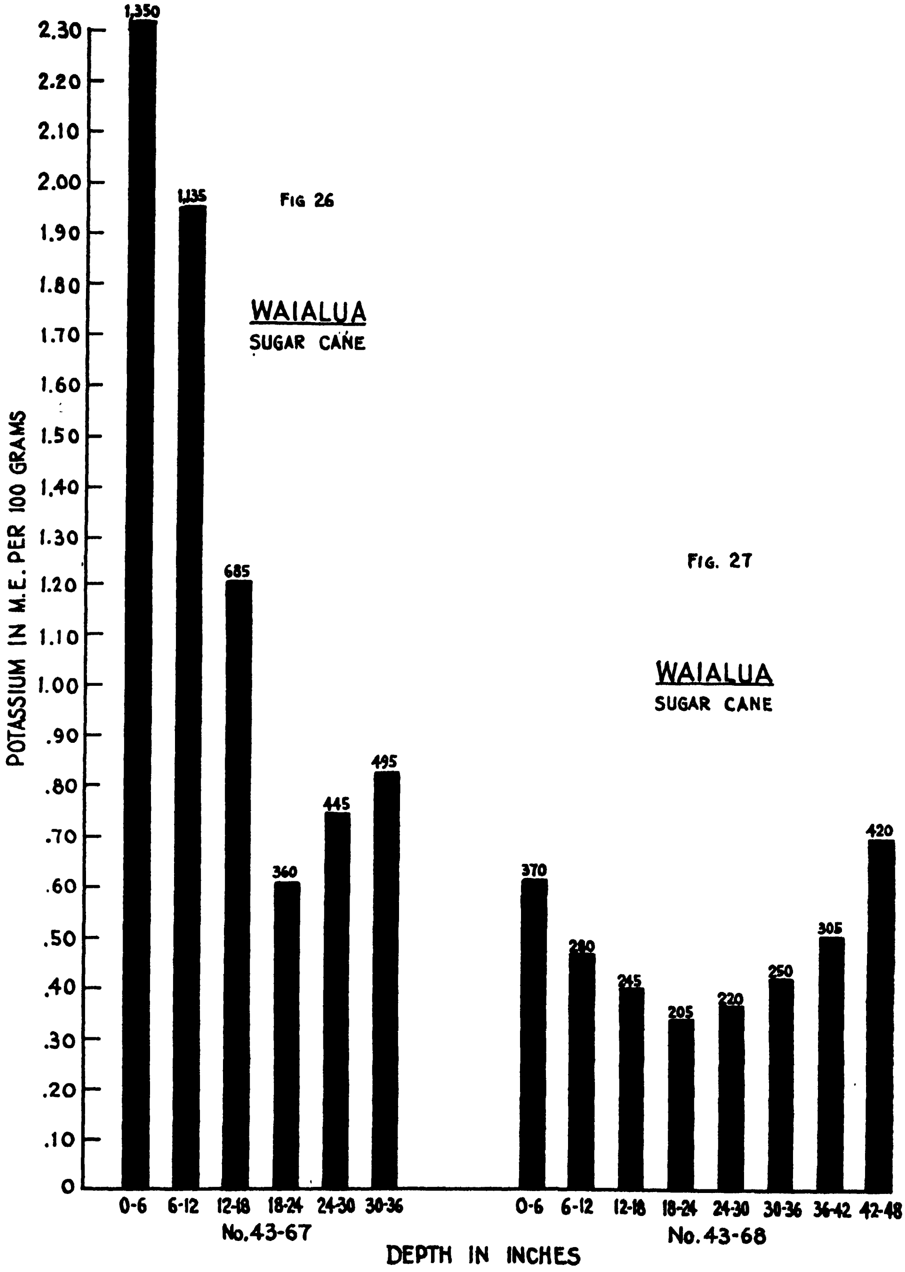

Fig 26

Fig. 27

POTASSIUM IN M.E. PER 100 GRAMS
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
WAIALUA
SUGAR CANE
1,350
1,135
685
360
445
495
0-6
6-12
12-18
18-24
24-30
30-36
No.43-67
WAIALUA
SUGAR CANE
370
280
245
205
220
250
305
420
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No.43-68
DEPTH IN INCHES

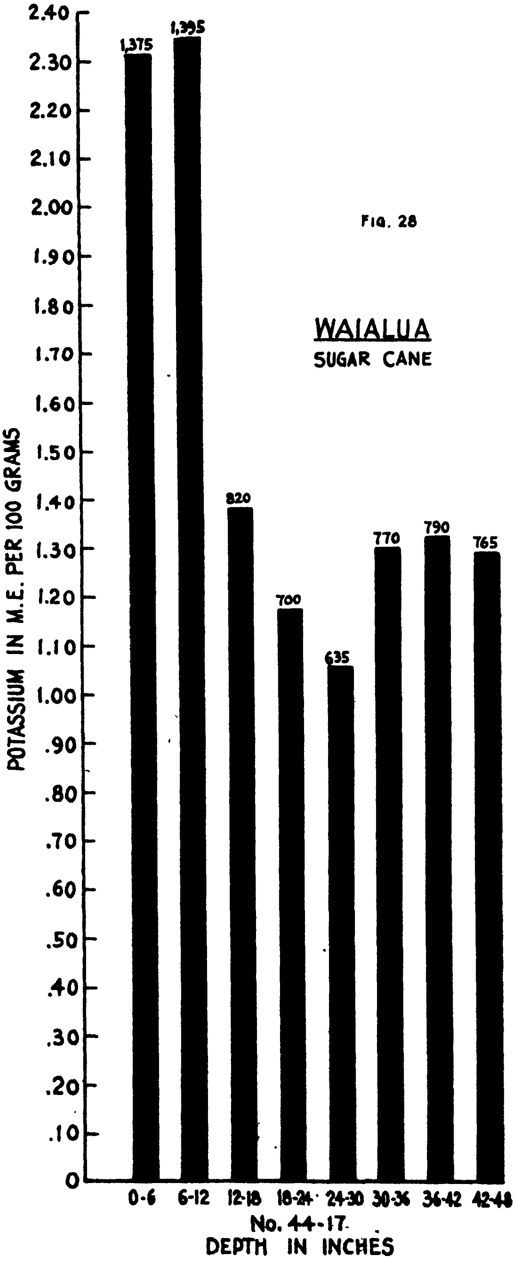
FIG. 28
WAIALUA
SUGAR CANE
POTASSIUM IN M.E. PER 100 GRAMS
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
1,375
1,395
820
700
635
770
790
765
0-6
6-12
12-18
18-24
24-30
30-36
36-42
42-48
No. 44-17
DEPTH IN INCHES

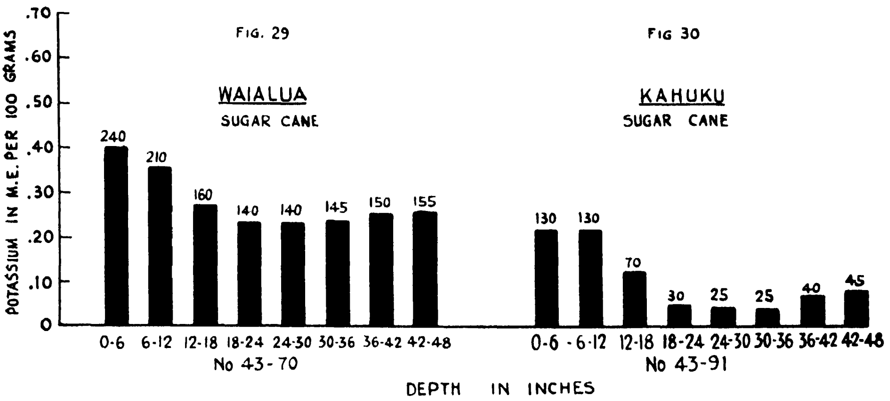

FIG. 29

WAIALUA

SUGAR CANE

FIG 30

KAHUKU

SUGAR CANE

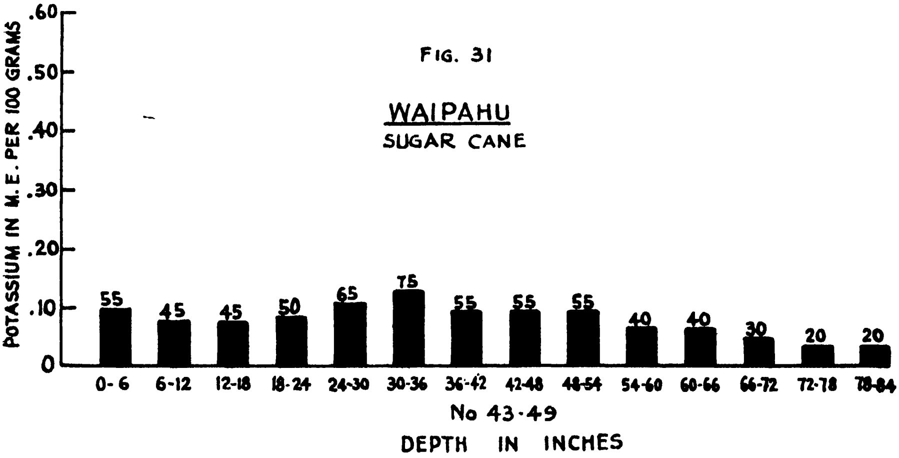

FIG. 31

WAIPAHU

SUGAR CANE

# A Search for Guidance in the Nitrogen Fertilization of the Sugar Cane Crop

## Part II—The First Ratoon Crop

---

By R. J. BORDEN

*A second series of measurements and analyses which have now been made on representative samples of 32–8560 cane taken from the first ratoon crop of Waipio Experiment 108 ATN has supplied further evidence in our search for guidance in the nitrogen fertilization of the sugar cane crop. Additional supplementary information about the nature of the development of this cane variety and of its composition at progressive growth stages has been accumulated and studied, and the many interesting relationships found have added much to our general knowledge. As yet, however, we have not been wholly successful in identifying definite levels or percentages of nitrogen or of other components which can be depended upon for assurance that their adjustment, by means of additional nitrogen applications, will give us the desired results, i.e., more sugar. But our search continues!*

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## INTRODUCTION

In Part I of this investigation we reported* many measurements and analyses made from the 32-8560 plant cane of a nitrogen experiment grown at Waipio and sampled periodically during its development. In this Part II we shall present many similar data obtained from the first ratoon crop grown on the identical area of the plant crop, and in general following a similar plan and procedure; major differences will be pointed out as the discussion proceeds.

## THE PLAN AND PROCEDURE

### 1. *The Plan:*

The experimental area has previously been described. After the harvest of the plant crop the area was cleaned up, the lines reshaped and the ditches repaired. Irrigation followed immediately and the crop was officially started on May 25, 1942; this was in contrast to the slightly later start (August 1) which the plant crop had. All blank spaces in the cane rows were replanted with good 32-8560 seed pieces within the following 10 days.

The specific fertilizers for this ratoon were applied by hand according to the following plan:

---

* **Borden, R. J., 1942. A search for guidance in the nitrogen fertilization of the sugar cane crop. Part I—The plant crop. The Hawaiian Planters' Record, 46: 191-238.**

| Plot identity | No. of plots | Appl. no. 1 7/1/42 | Appl. no. 2 9/10/42 | | Appl. no. 3 10/23/42 | Appl. no 4 4/27/43 | Total per acre | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Lbs. N | Lbs. N | Lbs. $K_2O$ | Lbs. N | Lbs. N | Lbs. N | Lbs. $P_2O_5$ | Lbs. $K_2O$ |
| A.......... | 8 | 40 | 60 | 100 | 0 | 0 | 100 | 0 | 100 |
| B.......... | 8 | 40 | 60 | 100 | 0 | 60 | 160 | 0 | 100 |
| C.......... | 8 | 40 | 60 | 100 | 60 | 0 | 160 | 0 | 100 |
| D.......... | 8 | 40 | 60 | 100 | 60 | 60 | 220 | 0 | 100 |

In addition, the same 3 "X" plots which had received no nitrogen during the plant crop were again included and again received no nitrogen.

When the crop was two months old ten sampling stations were carefully chosen and pinned out in each plot. Each station consisted of a solid stand in a five-foot row of cane containing no replant and enjoying no advantage from its proximity to the slower-developing replant. It was from one of these stations in each plot that all cane stalks were cut to provide the cane samples in the periodic harvests which followed at the ages of 3½, 5½, 7½, 8½, 9½, 10½, 11½, 14½, 17½ and 20½ months.

Irrigation intervals close to 250 day-degrees were maintained until November 27, 1943 when irrigation was stopped. Total rainfall between this date and final harvest of the field amounted to 7.6 inches, with another 2.0 inches falling while this harvest was in progress.

2. *Observations and Comments at Periodic Harvests:*

*At first preharvest at 3½ months:* (1) The ratoon crop had made rapid growth from its initial 40 pounds of nitrogen and had already produced some fair-sized stalks. Tillering had been heavy and the selected sampling areas were carrying better than ten stalks* per foot of row. Great variation in individual stalk development was apparent and the 32 specific five-foot sampling areas, which had been previously chosen for their similarity of stand, now showed tremendous growth differences; in total green weight, these actually ranged from 12.8 to 57.8 pounds or equivalents of from 11 to 51 tons per acre. (2) The replant was slow and much was in danger of being handicapped by the adjacent ratoon growth. (3) A definitely lighter green leaf color and an inferior growth was apparent on the "X" or "no N" plots. (4) No evidence of a residual effect from the plant crop's treatments was to be seen.

*At second preharvest at 5½ months:* (1) The cane except in the "no N" plots had now "covered in," some dry-leaf cane stalk had been formed, and many small shoots were dying off. (2) Leaf color was exceptionally good, *i.e.*, a dark green, and both leaves and stalks were extremely succulent. (3) The growth of primary stalks now appeared more uniform.

*At third preharvest at 7½ months:* (1) As a result of the heavy rains in December many stalks had already "gone down." (2) A few suckers had now made their first appearance. (3) The stand was now approximately five stalks per foot of row, and there were very few live stalks without some millable cane at this harvest.

*At fourth harvest at 8½ months:* (1) Most of the canes were now recumbent and the first record of dead primaries was made. (2) Suckers were more numerous on the plots which had received the larger nitrogen application. (3) The cane was still very succulent and had good leaf color; it still lacked creditable sweetness.

---

* Showing at least three nodes.

*At fifth harvest at 9½ months:* (1) Primary stalks which had not yet made millable cane were now dead, and there were now only about three to four stalks with millable cane per foot of row. (2) Suckers were increasing in numbers and growing rapidly; some had even developed a few feet of millable cane. (3) Millable canes were now definitely sweet. (4) Leaf color was still excellent, although that of cane which had received only 100 pounds of nitrogen was lighter than that of the more heavily (160 pounds) fertilized cane.

*At sixth harvest at 10½ months:* (1) The difference in leaf color between the 100 and 160 pounds N treatments was quite pronounced. (2) Suckers continued to increase and were definitely more numerous on plots of the higher nitrogen treatment where there were also more dead primary stalks.

*At seventh harvest at 11½ months:* (1) All plots now show a large number of suckers, both more and farther advanced in development than in the previous harvest; the tops of some of these suckers have already been shaded out and are dead. (2) Variation between replicate samples is again very great.

*At eighth harvest at 14½ months:* (1) The number of live and of dead primary stalks with millable cane has not changed much since the 5th harvest, but the suckers have steadily increased until they now amount to nearly 40 per cent of the total number of millable stalks; many of these millable suckers are of large diameter, and their dry-leaf section contains much sugar (Brix at 20).

*At ninth harvest at 17½ months:* (1) An idea of the great variation between replicates at this harvest may be gained from the following:

| Treatment | No. of replicates | Range in number of stalks within 5 feet of cane row | | | Range in equivalent tons per acre yields of millable cane (net area basis) |
|---|---|---|---|---|---|
| | | Primaries | Suckers | Dead | |
| X................ | 3 | 9–17 | 3–10 | 0 | 37–82 |
| A................ | 8 | 11–27 | 3–13 | 1–6 | 74–162 |
| B................ | 8 | 8–30 | 4–23 | 2–11 | 79–293 |
| C................ | 8 | 7–20 | 5–23 | 1–14 | 82–193 |
| D................ | 8 | 9–21 | 4–17 | 3–11 | 79–202 |

*Note:* The outstanding "5-foot of row" cane sample came from Plot 34B at 17½ months. It included 22 primary stalks, 28 suckers (only 2 of which were without millable cane) and 8 stalks with dead tops; a total of 53 stalks or 10.6 per foot of row.

(2) The tops were generally small and the leaves badly shredded. (3) Except in the "X" plots there were many dead primary stalks, most of which had developed "splits" some time previous.

*At tenth harvest at 20½ months:* (1) The tops especially of primary stalks were all quite small. (2) The great variation in replicates continues. (3) Heavy suckering was found especially in the high-nitrogen "D" plots. (4) There were many dead stalks including some suckers which had made several feet of millable cane.

3. *Experimental Procedure:*

The monthly collection of soil samples and of leaf-punch samples for subsequent nitrogen analyses followed the same procedure that was used in the plant crop. This was also true of the collection and preparation of the ten preharvest cane samples so that they would again be truly representative of the crop in their respective field plots.

Records of total green weight and of millable cane were secured at each preharvest and are reported on their equivalent tons per acre (net area) basis. At the same time, a complete census was made of all stalks cut from each sampling station, and on the basis of this census, duplicate cane samples were made up for further processing. One of these samples after being topped was milled in the Waipio Cuban A mill and the crusher juice therefrom analyzed for nitrogen and yield of commercial sugar. The duplicate cane sample (but not topped) was prepared for laboratory analyses. These laboratory samples of the total green weight from each plot were analyzed by standard chemical methods for total nitrogen, phosphoric acid, potash, moisture, reducing sugars, sucrose, and fiber. Chlorophyll determinations and studies of leaf-sheath composition were not included in this year's study.

All measurements and analytical data from the eight replicates of the four treatments which received nitrogen fertilizer were again subjected to statistical study by the "analysis of variance" to determine what degree of reliability might be placed on differences due to treatment.

4. *Monthly Soil Analyses (Fig. 1):*

Soil samples were taken monthly to a depth of 12 inches in the area midway between the rows of cane from a series of "no-nitrogen" and "high nitrogen" plots. These were tested immediately by our modified Mitscherlich test and the results which are shown graphically in Fig. 1 indicate the status of the available soil nitrogen content in this experimental area while the ratoon crop was being grown.

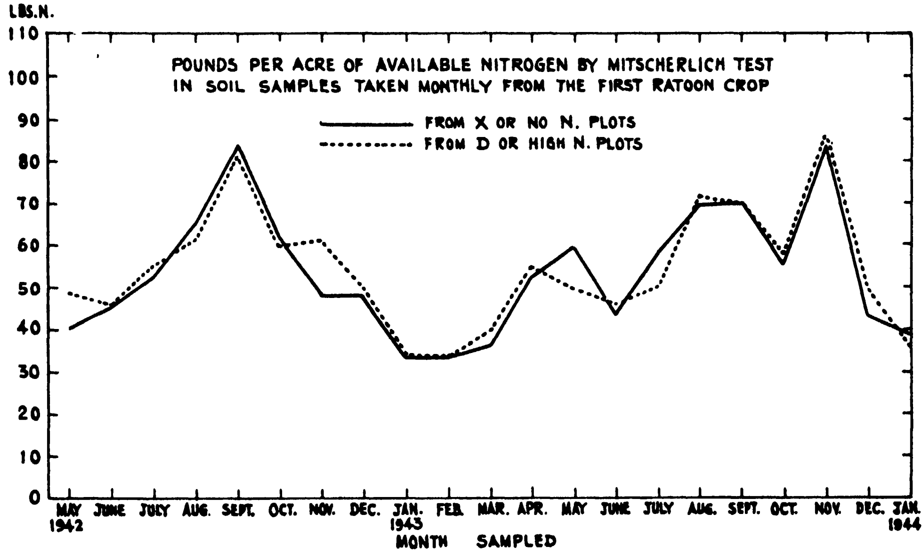

Fig. 1.

The similarity between the two curves in Fig. 1 offers convincing evidence that the effects are natural soil effects and not an influence of applied nitrogen fertilizer. The first sample from this ratoon crop showed a nitrogen availability which was quite comparable to that secured from the last sample which had been taken from the preceding crop. Thereafter there was an increase in the available nitrogen supply until the cane was almost covered in and its roots had spread laterally well into the row middles. At this time, there began a rapid falling off in the amount of soil nitrogen with a low point of 30–35 pounds per acre being reached in January when the crop was 7½ months old. Unlike the corresponding result from the plant crop however, this low-nitrogen level was not maintained through the rest of the growing period but it started to increase with the advent of spring, and with a few exceptions continued its upward trend for six or eight months more.

The reasons for this increase in available nitrogen from the soil's natural supply are not known. It occurred right after the cane had "gone down" and again exposed some of the surface soil areas to more air and sun, for the trash blanket at this time was not extra heavy. But whatever the reason, the fact is clear that soil nitrogen did contribute something to this ratoon crop during its second year of growth—a contribution that was not found as definitely during a corresponding period in the plant crop from the same area.

## TREATMENT EFFECTS

### 1. *Their Reliability:*

In spite of our initial efforts to select a series of comparable cane sampling stations in the field plots, subsequent natural variations in growth largely offset our good intentions.

Thus the analysis of variance has again indicated some high residual errors in cane weights and calculations based thereon, and our eight replicates have been generally inadequate in establishing reliable significance to many quite large treatment differences at the periodic harvests. However, although many large differences between treatment averages are shown with a tag of "non significance," a careful rationalization of the data will often give a logical interpretation that may at least be tentatively accepted.

In Table I we have summarized the coefficients of variation (based on the residual error variance) for the different measurements and analyses that were made at each harvest. They offer some interesting evidence: for instance, the coefficients of variation for all measurements under "tons per acre" and "pounds per acre" are high, and indicate the extreme variability in weights even in carefully harvested replicates of sugar cane field samples. The variation in the composition of these variable cane samples is, however, considerably lower for most of the measurements made. Thus the very low coefficients of variation for per cent moisture indicate great uniformity in this component of the sugar cane crop. The C. V.'s for fiber also indicate quite a satisfactory uniformity. On the other hand there is evidence of wide variation in the percentage of reducing sugars between the replicate cane samples; this is especially noticeable at the 5th, 6th, and 7th harvests when the stalk population was changing and sucker growth was booming. In the per cent sucrose and per cent total sugars, the replicates show a very fair similarity especially after the crop has become well established. For their major nutrient composition (per cent N, $P_2O_5$, $K_2O$) the replicated total cane samples show a variation which might be a reflection of the age differences in their stalk populations—thus an indirect effect from the wide variation in the total cane weights.

The replicate analyses for per cent N from the crusher juice samples were extremely variable at every harvest, and it is quite apparent that this analysis is less dependable for comparative purposes than the corresponding N analysis made from the total cane sample.

The generally low coefficients of variation for per cent N in the leaf-punch samples speak well for the uniformity of the plant material from which these samples were taken. This makes it apparent that it will be easier to duplicate the nitrogen analyses from properly taken leaf-punch samples than from either total green weight or crusher juices.

TABLE I

COEFFICIENTS OF VARIATION

| Measurements | Harvest No.: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Month: | Sept. | Nov. | Jan. | Feb. | Mar. | Apr. | May | Aug. | Nov. | Feb. |
| | Age (mos.): | 3½ | 5½ | 7½ | 8½ | 9½ | 10½ | 11½ | 14½ | 17½ | 20½ |
| *In tons per acre:* | | | | | | | | | | | |
| For total green weight | | 35.5 | 24.1 | 16.7 | 22.9 | 22.5 | 19.7 | 38.8 | 22.1 | 33.2 | 31.2 |
| For total dry weight.. | | 33.2 | 25.9 | 17.8 | 25.0 | 25.1 | 19.9 | 38.2 | 22.4 | 33.3 | 32.3 |
| For total red. sugars . | | 45.2 | 27.4 | 20.7 | 21.9 | 29.5 | 34.1 | 52.4 | 28.4 | 42.8 | 47.4 |
| For total sucrose ..... | | 43.8 | 30.7 | 21.9 | 28.4 | 24.9 | 19.5 | 39.4 | 22.6 | 33.3 | 32.0 |
| For total sugars...... | | 44.5 | 28.6 | 20.0 | 27.3 | 24.5 | 19.6 | 39.5 | 22.2 | 32.5 | 31.7 |
| For millable cane .... | | 44.6 | 26.9 | 17.2 | 23.9 | 22.3 | 19.0 | 39.3 | 22.7 | 34.0 | 32.7 |
| For commercial sugar . | | 250.0 | 59.7 | 29.5 | 36.3 | 26.3 | 23.1 | 39.0 | 23.1 | 34.1 | 34.4 |
| *In pounds per acre:* | | | | | | | | | | | |
| For $P_2O_5$ in total cane | | 26.2 | 23.6 | 21.6 | 29.2 | 26.8 | 23.7 | 40.5 | 23.9 | 35.5 | 34.6 |
| For $K_2O$ in total cane | | 37.3 | 23.3 | 25.3 | 26.6 | 22.3 | 27.0 | 40.8 | 19.8 | 30.8 | 33.1 |
| For N in total cane... | | 29.2 | 26.4 | 21.6 | 22.5 | 25.9 | 22.2 | 37.2 | 22.6 | 33.3 | 37.9 |
| *In total cane harvested:* | | | | | | | | | | | |
| For % tops.......... | | 12.0 | 12.9 | 11.7 | 15.8 | 7.5 | 13.1 | 10.7 | 10.8 | 14.8 | 14.7 |
| For % moisture...... | | 1.3 | 1.1 | 1.1 | 1.6 | 1.5 | 1.4 | 1.9 | 1.7 | 1.4 | 2.1 |
| For % fiber ......... | | 6.9 | 5.5 | 4.6 | 7.0 | 6.6 | 6.3 | 6.5 | 4.6 | 5.5 | 6.1 |
| For % red. sugars.... | | 17.0 | 16.6 | 13.9 | 17.8 | 30.6 | 25.4 | 31.3 | 18.2 | 21.4 | 38.9 |
| For % sucrose ....... | | 14.9 | 8.6 | 11.7 | 8.6 | 4.9 | 7.9 | 5.6 | 6.1 | 4.1 | 6.1 |
| For % total sugars... | | 4.1 | 7.9 | 9.6 | 7.0 | 4.9 | 7.2 | 5.2 | 5.0 | 6.4 | 5.5 |
| For % $P_2O_5$ ......... | | 12.9 | 9.3 | 11.5 | 13.6 | 10.9 | 8.5 | 15.5 | 10.4 | 10.1 | 13.4 |
| For % $K_2O$.......... | | 13.6 | 10.1 | 15.6 | 19.5 | 15.1 | 16.5 | 15.6 | 13.9 | 9.8 | 13.7 |
| For % N............ | | 8.8 | 13.1 | 9.6 | 11.3 | 12.1 | 8.8 | 12.9 | 12.5 | 10.4 | 15.8 |
| *In % N in leaf-punches..* | | 4.0 | 2.1 | 1.1 | 1.5 | 1.4 | 2.3 | 2.3 | 3.5 | 5.2 | 4.8 |
| *In % N in crusher juice..* | | 21.4 | 29.2 | 20.8 | 20.7 | 32.0 | 34.6 | 21.7 | 23.1 | 21.4 | 20.0 |
| *In yield % cane.........* | | 20.0 | 47.1 | 19.5 | 17.0 | 8.5 | 13.1 | 8.7 | 14.3 | 12.5 | 10.2 |

### 2. *On the Stalk Population (Fig 2):*

A census of the stalk population which was made at each preharvest gives an interesting picture of the changes that took place in the composition of the crop as it developed and shows some rather definite influences of the nitrogen fertilizations, particularly those which were made in April to cane which was 11 months old. Especially notable is the greater increase in the number of suckers with millable stalk at 14½ and 17½ months that resulted when the April nitrogen application was made to cane which had received only 100 pounds of N previously, than to cane which had already received 160 pounds. This influence is quite clearly shown in the two upper graphs in Fig. 2 (compare B over A with D over C), and it possibly indicates an influence from the timing of the nitrogen fertilization, because the earlier or October application did not give us the same clear-cut differences between Treatments C and A that the later or April application made between B and A.

The lower graph in Fig. 2 shows that the large applications of nitrogen have resulted in more stalks with dead tops at 17½ and 20½ months. The actual numbers at the last harvest seem large, averaging approximately one-third of the total number of canes which had made millable stalk. Some of them had been dead and

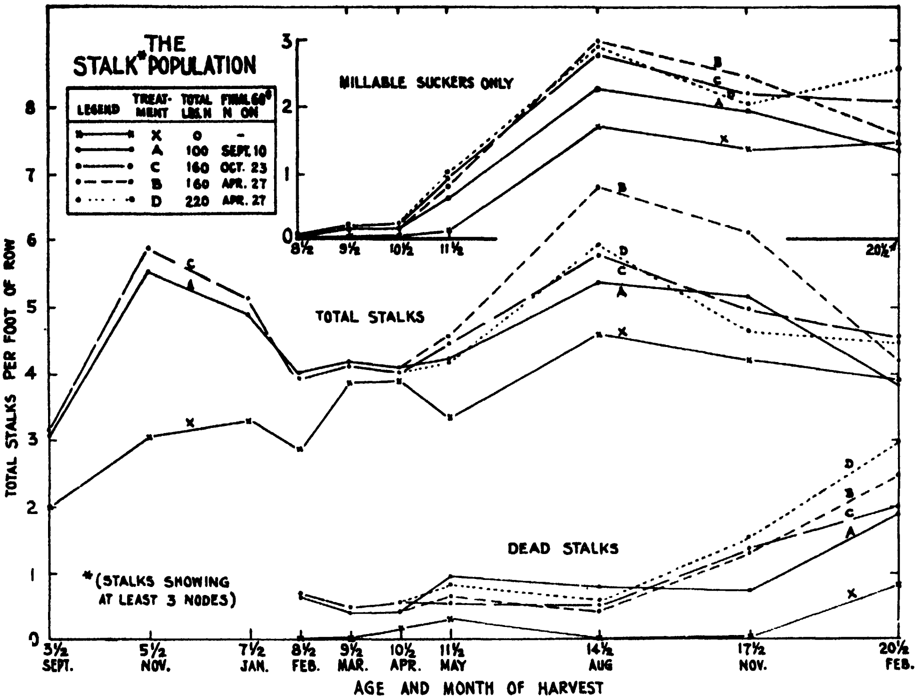

Fig. 2.

dry for many months, whereas others were in various earlier stages of decomposition.

It should be apparent that these two factors—number of suckers with more or less millable cane, and of dead or dying stalks at harvest—can have a considerable effect on the crop's crusher juice quality, and since both of them are influenced by the nitrogen fertilization, a large part of the well-recognized effect of nitrogen on crusher juices may be due to its direct influence on the stalk population.

3. *On Total Green Weights (Fig. 3) (Table 1 in Appendix):*

Yields of total green weight from this first ratoon crop were again influenced by the nitrogen fertilizations. The "C" plots which received an additional 60-pound application of N late in October were rather slow to respond during the winter but by spring they jumped ahead and thereafter maintained their increases over the "A" plots which had been supplied with only the basic amount of 100 pounds. The "B" plots with their extra 60 pounds of N applied late in April immediately picked up weight and held a big lead over the "A" plots. A second additional 60-pound application made in April to create Treatment "D" also increased yields over Treatment "C's" total of 160 pounds but it is very doubtful whether Treatment "D" which received a total of 220 pounds of N produced any more vegetative growth than Treatment "B" which had been given only 160 pounds.

When discussing the plant crop we called attention to the nature of the production of total green weight, i.e., its rapid increase up to the time when it was 5½ months old, its apparent slowing up when only 7½–9½ months old, and its accelerated rate of production thereafter until it was dried off for harvesting. For this

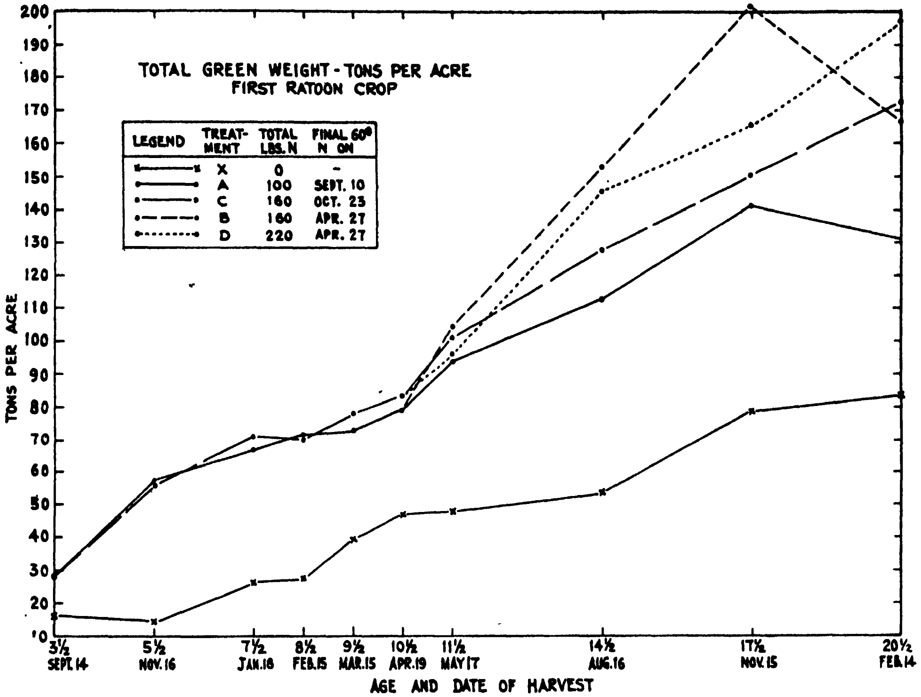

Fig. 3.

ratoon crop, we find a similarity with the plant crop in its vegetative development, even though the average effect occurred under slightly different seasonal conditions. If we had not already noted the slowing up in the plant crop between 7½ and 9½ months during March-May, we might imply that the slow up of the ratoons at this age in January-March was due to its winter check in growth, but it is now thought that the crop age probably dominates the seasonal effect upon crop development.

4. *On Percentage of Tops (Table 2 in Appendix):*

The effects from all four nitrogen treatments upon the percentage of tops in the total green weight were very similar. Thus from all of the N-fertilized plots, we harvested cane which had 30 per cent tops at 5½ months, 20 per cent tops at 11½ months, and not much more or less than 10 per cent tops at 17½ months and at the final harvest. These figures compare very well with those from the plant crop, except at 5½ months when the plant crop had 40 per cent of its green weight as tops.

5. *On Per Cent Moisture in Total Green Weight (Fig. 4) (Table 3 in Appendix):*

The higher nitrogen applications have again produced cane crops with a higher moisture content. For the first 7½ months the nitrogen-fertilized cane carried around 80 per cent moisture, thereafter it dropped to less than 75 per cent. The 60-pound nitrogen applications that were made in April effected an immediate increase in the moisture content of Treatments B and D over Treatments A and C respectively. The slight increase in moisture of the crops which did not get any additional nitrogen in April is probably due to the increased sucker growth which

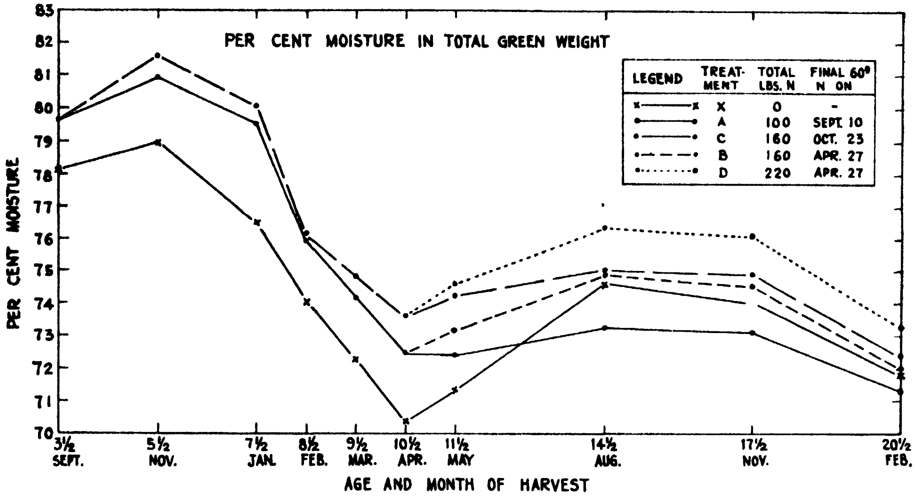

Fig. 4.

was becoming more obvious; this is indicated by the fact that the number of non-millable suckers was at its peak in May at 11½ months, and that the peak for suckers with millable cane was reached three months later.

6. *On Per Cent Fiber in Total Green Weight (Fig. 5) (Table 4 in Appendix):*

A study of the percentages of fiber in the total green weight harvested tends to show an effect from the nitrogen applications that is almost the reverse of what we found for the moisture relations. The higher applications appear to have produced a crop with a lower percentage of fiber and as was the case with moisture, these effects have occurred quickly.

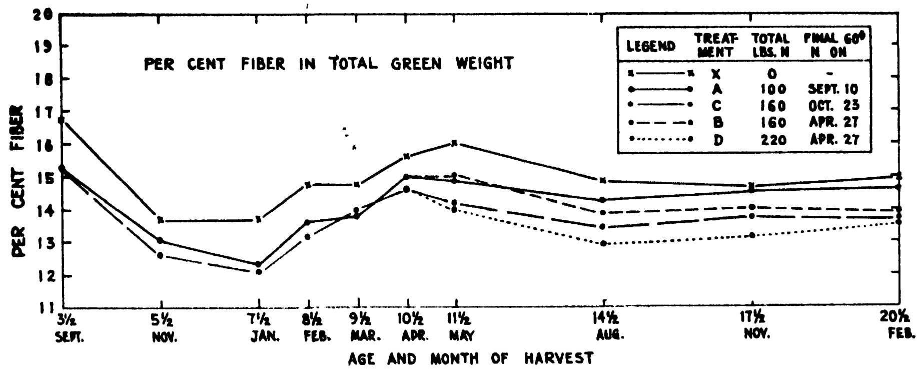

Fig. 5.

7. *On Total Dry Weight (Fig. 6) (Table 5 in Appendix):*

The relationships between the treatment effects on the total dry weights follow quite closely those already discussed under total green weight. There is this difference however—the decreased rate of production of total green weight between 7½ and 9½ months is not apparent in the dry weight; in fact the production of total dry matter was at pretty close to a constant rate throughout the entire growing

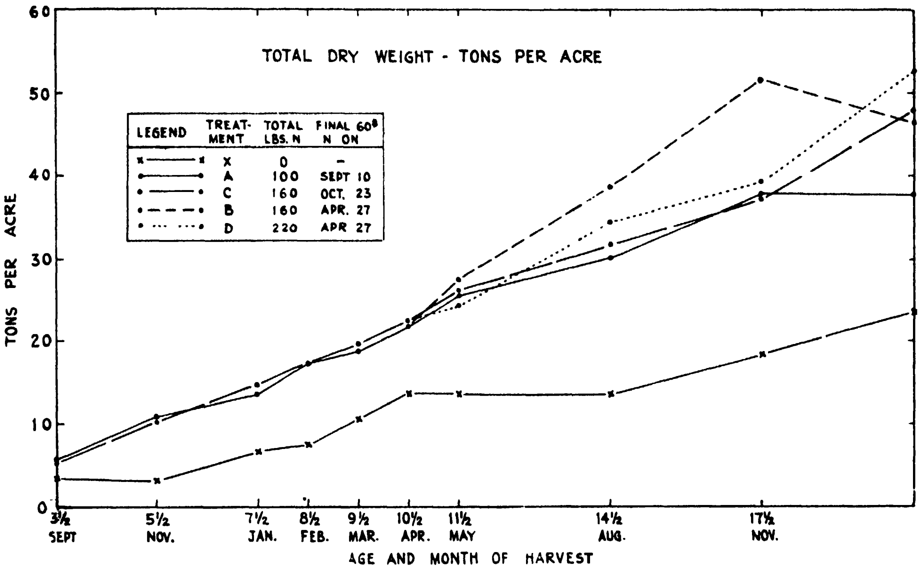

Fig. 6.

period, except for Treatment B which seemed to get an accelerated spurt from its April nitrogen application. Apparently then, the aforementioned slow up in green-weight production was largely an effect from its decreased moisture content that we recorded for this same period.

8. *On the Composition of the Total Dry Weight:*

(a) *Per cent reducing sugars (Fig. 7) (Table 6 in Appendix):* The effect from the different nitrogen treatments upon the percentage of reducing sugar is again a very definite and positive one; each increase in nitrogen fertilizer has caused an immediate and corresponding increase in the concentration of these sugars in the crop produced. In spite of the high experimental error associated with this measurement the treatment differences in the last four harvests are highly significant.

As was the case in the plant crop, we again note that the generally high concentrations of reducing sugar found in the first few harvests drop quite sharply and in all treatments are at a low level when the crop is 9½ to 11½ months old. Thereafter their increase is probably associated with the rapid development of the sucker growth which occurred between 11½ and 14½ months. The more gradual reduction which comes with the increased crop age eventually brings all but the high-nitrogen treatment (D) to less than two per cent at the final harvest.

(b) *Per cent sucrose (Fig. 8) (Table 7 in Appendix):* The effect of nitrogen on the percentage of sucrose, although not as clear as the effect on reducing sugars, is nevertheless quite the opposite, for we find a lower per cent sucrose in the higher nitrogen-fertilized cane. These undesirable effects from increased nitrogen are quite significant especially in those later harvests that were made before any attempts were made to "dry off" the field.

The increase in sucrose concentration from all treatments was very rapid during the first fall and winter months before the cane was 7½ months old. After this there was but little further change during the spring and summer, but another in-

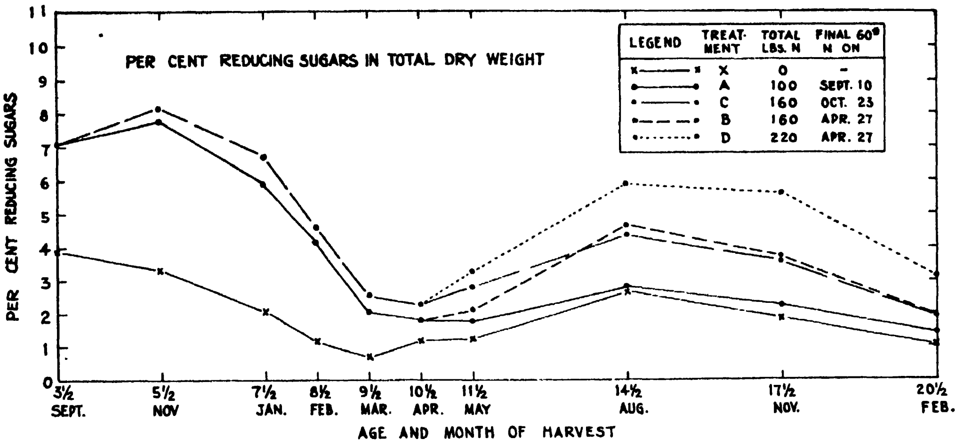

Fig. 7.

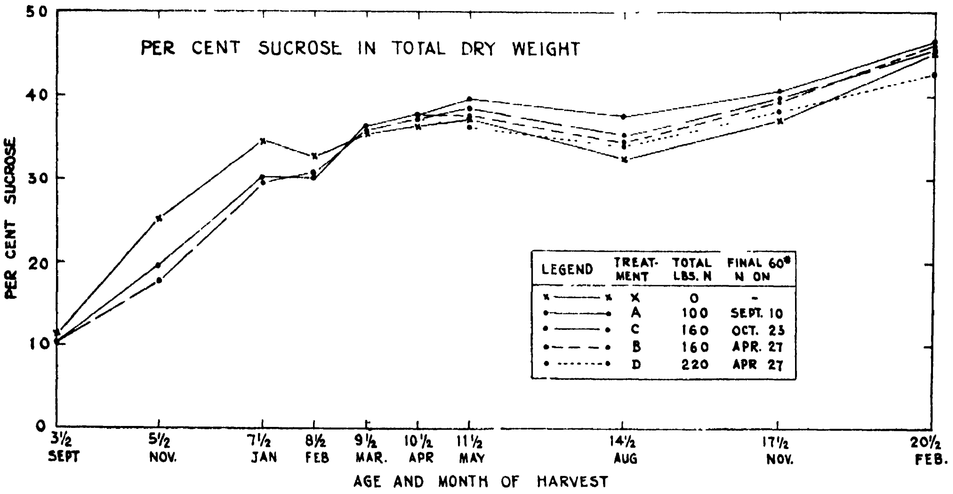

Fig. 8.

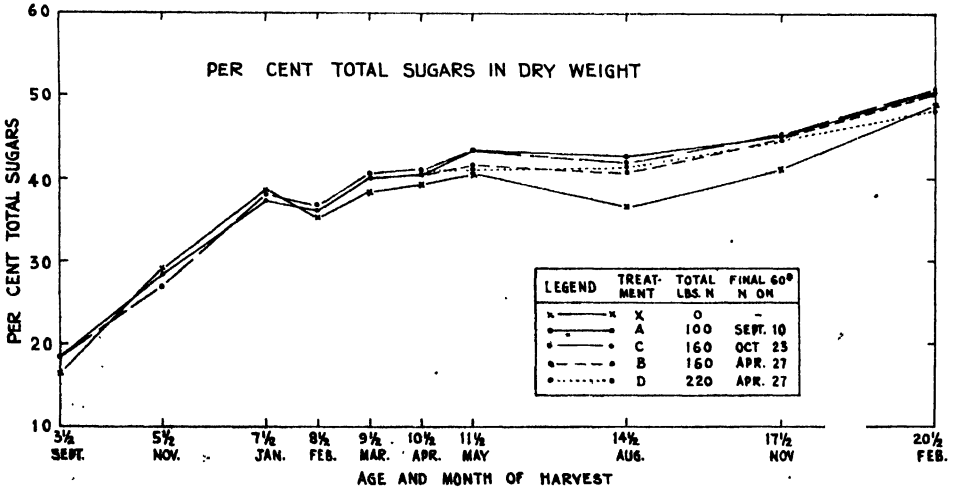

Fig. 9.

crease which started in the second fall continued to the final harvest in February. These results suggest seasonal effects on this component of the sugar cane crop.

(c) *Per cent total sugars (Fig. 9) (Table 8 in Appendix):* The concentration of the total sugars in this crop was apparently not differentially influenced by the nitrogen fertilization. This fact tends to confirm an opinion we advanced when similar results were found from the plant crop—i.e., some factor other than nitrogen has a greater influence on the percentage of total sugars. We are inclined to think that this may be largely an age factor since the rapid increase, which occurred in the concentration of total sugars between September and January for this crop, compares with a similar increase obtained between November and March for the plant crop, from cane which in both instances was between 3½ and 7½ months old. Another increase came between the ages of 14½ and 20½ months for both crops; in this ratoon crop these ages occurred between August and February whereas in the plant crop they came between October and April.

(d) *Per cent nitrogen (Fig. 10) (Table 9 in Appendix):* All nitrogen applications had an immediate effect upon the percentage of nitrogen in the total dry weight. Each additional amount of nitrogen applied produced a significant increase in the nitrogen concentration of the plant. In the fertilized canes this nitrogen concentration was highest at the age of 5½ months in November. It declined at a very constant rate during the following six months and thereafter remained at its relatively low level for the remainder of the crop.

At the age of 7½ months (in January) Treatment A which had received nitrogen at the rate of only 100 pounds per acre had .46 per cent N in its total dry weight, whereas the nitrogen in Treatment C which had received 160 pounds N per acre was at .59 per cent N. At 10½ months (in April) Treatment A had dropped to .29 per cent and Treatment C to .37 per cent N.

In our search for guidance in nitrogen fertilization, these latter figures need careful study for their relations with the actual yields secured from the field plots at their harvest at 22 months, and also for their comparison with similar relations established from the plant crop. To facilitate such a study we have prepared Table 11. In the plant crop, .34 per cent N in the total dry weight at 10½ months was below the critical limit because an additional 60-pound application of nitrogen resulted in a significant increase in sugar; on the other hand a level at .43 per cent N for this same age was apparently adequate for the additional 60 pounds of nitrogen at 11 months did not give further increases in yields. In this ratoon crop although the gains measured were not statistically significant, it may be tentatively assumed that both .29 per cent N and .37 per cent N which were found in the dry weight at 10½ months indicate an inadequate concentration to carry the crop for another 10½ months because the nitrogen fertilizer added at 11 months appears to have given increased sugar yields in both cases. This makes it look as though .37 per cent N in the dry weight is below the critical level for 10½ months cane.

The fact that the last 60-pound application of nitrogen was equally effective on the final sugar yields from cane which had received both 160 and 100 pounds leads one to assume that the similarity in the final sugar yields from Treatments B and D ratoons indicates that their differences in the early nitrogen applications, *i.e.,* 100 vs. 160 pounds had not had much effect upon their yields within the first 10½ months. This fact is nicely shown in Fig. 14.

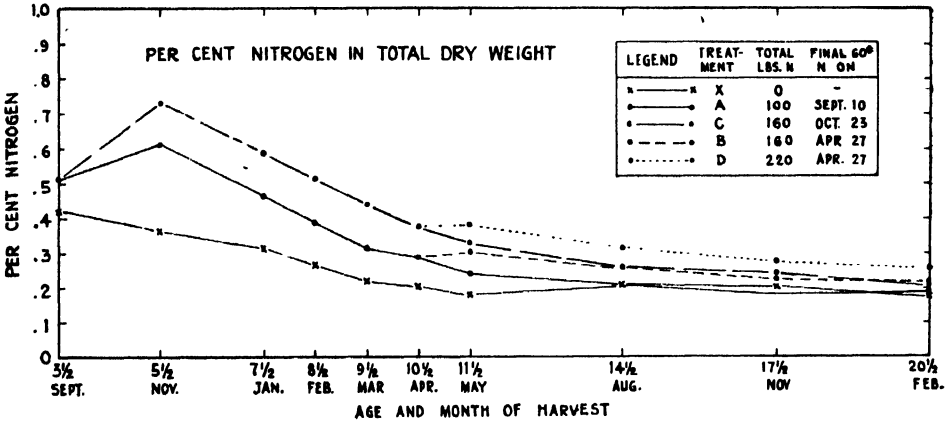
PER CENT NITROGEN IN TOTAL DRY WEIGHT
PER CENT NITROGEN
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
LEGEND
TREATMENT
TOTAL LBS. N
FINAL 60# N ON
X
0
-
A
100
SEPT. 10
C
160
OCT. 23
B
160
APR 27
D
220
APR. 27
3½ SEPT.
5½ NOV.
7½ JAN.
8½ FEB.
9½ MAR
10½ APR.
11½ MAY
14½ AUG.
17½ NOV
20½ FEB.
AGE AND MONTH OF HARVEST

Fig. 10.

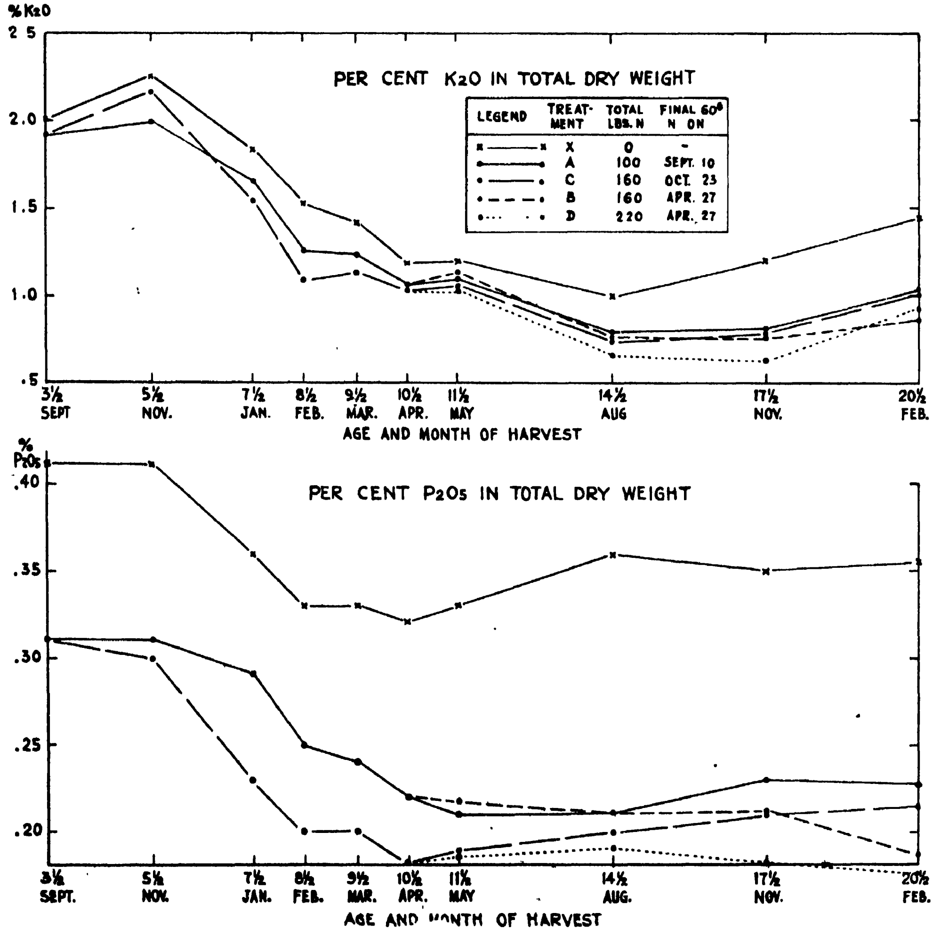
% K2O
2.5
2.0
1.5
1.0
.5
PER CENT K2O IN TOTAL DRY WEIGHT
LEGEND
TREATMENT
TOTAL LBS. N
FINAL 60# N ON
X
0
-
A
100
SEPT. 10
C
160
OCT. 23
B
160
APR. 27
D
220
APR. 27
3½ SEPT
5½ NOV.
7½ JAN.
8½ FEB.
9½ MAR.
10½ APR.
11½ MAY
14½ AUG
17½ NOV.
20½ FEB.
AGE AND MONTH OF HARVEST
% P2O5
.40
.35
.30
.25
.20
PER CENT P2O5 IN TOTAL DRY WEIGHT
3½ SEPT.
5½ NOV.
7½ JAN.
8½ FEB.
9½ MAR.
10½ APR.
11½ MAY
14½ AUG.
17½ NOV.
20½ FEB.
AGE AND MONTH OF HARVEST

Fig. 11.

## TABLE II

## RELATION BETWEEN PER CENT N IN DRY WEIGHT AT 10½ MONTHS AND THE FINAL FIELD YIELDS OF CANE AND SUGAR AT 22 MONTHS

| | | | At 10½ months | | | | Field yields at 22 mos. | | |
|---|---|---|---|---|---|---|---|---|---|
| Crop | No. of plots | Plot identity | Lbs. N applied | % N in dry wt. | Treatment | Additional N at 11 mos. (lbs.) | T.C.A. | Y%C | T.S.A. |
| Plant | 16 | A+B | 100 | .34 | A | 0 | 111 | 13.9 | 14.7 |
| | | | | | B | 60 | 120 | 13.2 | 15.7 |
| | 16 | C+D | 160 | .43 | C | 0 | 120 | 13.1 | 15.6 |
| | | | | | D | 60 | 123 | 12.7 | 15.5 |
| Ratoon | 16 | A+B | 100 | .29 | A | 0 | 115 | 11.1 | 12.7 |
| | | | | | B | 60 | 127 | 10.5 | 13.2 |
| | 16 | C+D | 160 | .37 | C | 0 | 126 | 10.1 | 12.6 |
| | | | | | D | 60 | 137 | 9.7 | 13.2 |

(e) *Per cent phosphoric acid and potash (Fig. 11) (Tables 10 and 11 in Appendix):* The increased applications of nitrogen have been responsible for a lowered concentration of both phosphoric acid and potash in the total dry weights harvested. Like nitrogen, the percentages of $P_2O_5$ and $K_2O$ were at their high point at 5½ months; thereafter they too declined and showed but little change after 11½ months.

The percentages of $P_2O_5$ were considerably higher in all harvests of this ratoon than from corresponding harvests of the plant crop, and this condition existed in spite of the fact that no phosphate fertilizer was applied for the ratoon crop. The $K_2O$ percentages found in this crop were in most cases slightly lower than those from the plant crop, although both crops had received a total of 100 pounds $K_2O$ per acre in their fertilizer.

(g) *Total nutrition and nutrition ratios:* In Table III we have again set down the percentages of N, $P_2O_5$, and $K_2O$ as found in the total dry weight from each harvest. The effects from the different nitrogen applications are quite apparent. Each increment of nitrogen supplied has increased the per cent nitrogen but decreased the per cent of both phosphate and potash. This same trend, though not as distinct, was noted in the plant crop. Knowledge of the fact that differences in the available nitrogen supply can affect the concentrations of $P_2O_5$ and $K_2O$ in the cane crop is going to place a considerable handicap on attempts to interpret these mineral plant food analyses.

Our attempts to interpret the sum total of the percentages of N, $P_2O_5$, and $K_2O$ as an index of total nutrition, and of their milli-equivalent ratios as indices of the quality of nutrition have not been especially successful. In almost every instance the total nutrition in the nitrogen-deficient cane (Treatment X) was actually higher than in the nitrogen-fertilized cane. Furthermore, differences in the total nutrition of the four nitrogen treatments were never large enough to be reliably identified with the amounts of nitrogen that had been made available for the crop. From the plant crop in which Treatment B gave the maximum sugar yields at the final harvest, we recorded the total nutrition just before harvest as 1.338 per cent and the quality of nutrition as 38–15–47. From the present ratoon crop, we find that the final sugar yield from Treatment B is associated with a total nutrition of 1.327 and a quality of nutrition of 35–18–47. The figures from these two crops appear to be quite similar and yet the sugar yield from the plant crop was 2½ tons greater.

TABLE III

NUTRIENT COMPOSITION OF TOTAL DRY WEIGHTS

| | | | Percentages in total dry weight | | | | | | Pounds per acre in total dry weight | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | Age (mos.) | Lbs. N to date | N | $P_2O_5$ | $K_2O$ | Sum ($N+P_2O_5+K_2O$) | Ratio* $N-P_2O_5-K_2O$ | $P_2O_5+K_2O \div N$ | Total lbs. N, $P_2O_5$, $K_2O$ | Proport. (%) N, $P_2O_5$, $K_2O$ |
| X | 3½ | 0 | .421 | .407 | 2.043 | 2.871 | 33–19–48 | 2.02 | 200 | 15–14–71 |
| A | " | 100 | .512 | .314 | 1.913 | 2.739 | 40–15–45 | 1.48 | 310 | 19–11–70 |
| X | 5½ | 0 | .356 | .410 | 2.270 | 3.036 | 28–19–53 | 2.58 | 187 | 12–13–75 |
| A | " | 100 | .617 | .306 | 1.991 | 2.914 | 44–13–43 | 1.26 | 624 | 21–11–68 |
| C | " | 160 | .731 | .298 | 2.168 | 3.197 | 47–11–42 | 1.13 | 663 | 23–9–68 |
| X | 7½ | 0 | .316 | .363 | 1.850 | 2.529 | 29–20–51 | 2.43 | 320 | 13–14–73 |
| A | " | 100 | .459 | .286 | 1.657 | 2.402 | 41–15–44 | 1.45 | 662 | 19–12–69 |
| C | " | 160 | .583 | .231 | 1.546 | 2.360 | 49–12–39 | 1.03 | 670 | 25–10–65 |
| X | 8½ | 0 | .265 | .333 | 1.527 | 2.125 | 29–21–50 | 2.46 | 312 | 12–16–72 |
| A | " | 100 | .387 | .251 | 1.264 | 1.902 | 43–16–41 | 1.36 | 645 | 20–13–67 |
| C | " | 160 | .516 | .198 | 1.088 | 1.802 | 54–12–34 | .86 | 612 | 29–11–60 |
| X | 9½ | 0 | .222 | .329 | 1.416 | 1.967 | 27–23–50 | 2.78 | 432 | 11–17–72 |
| A | " | 100 | .317 | .243 | 1.239 | 1.799 | 38–17–45 | 1.62 | 675 | 18–13–69 |
| C | " | 160 | .443 | .196 | 1.139 | 1.778 | 49–13–38 | 1.03 | 690 | 25–11–64 |
| X | 10½ | 0 | .203 | .318 | 1.190 | 1.711 | 27–25–48 | 2.68 | 479 | 12–18–70 |
| A | " | 100 | .286 | .221 | 1.076 | 1.583 | 39–18–43 | 1.58 | 702 | 18–14–68 |
| C | " | 160 | .374 | .179 | 1.037 | 1.590 | 47–14–39 | 1.11 | 702 | 24–11–65 |
| X | 11½ | 0 | .184 | .327 | 1.207 | 1.718 | 25–26–49 | 3.01 | 469 | 11–19–70 |
| A | " | 100 | .236 | .210 | 1.105 | 1.551 | 34–18–48 | 1.92 | 809 | 15–14–71 |
| B | " | 160 | .300 | .217 | 1.133 | 1.650 | 39–17–44 | 1.56 | 903 | 18–13–69 |
| C | " | 160 | .328 | .186 | 1.065 | 1.579 | 43–15–42 | 1.30 | 825 | 21–12–67 |
| D | " | 220 | .380 | .185 | 1.051 | 1.616 | 47–14–39 | 1.11 | 778 | 24–11–65 |
| X | 14½ | 0 | .207 | .359 | 1.024 | 1.590 | 29–29–42 | 2.50 | 426 | 13–23–64 |
| A | " | 100 | .205 | .209 | .788 | 1.202 | 36–22–42 | 1.75 | 716 | 17–17–66 |
| B | " | 160 | .256 | .207 | .758 | 1.221 | 42–20–38 | 1.36 | 937 | 21–17–62 |
| C | " | 160 | .255 | .202 | .757 | 1.214 | 42–20–38 | 1.35 | 776 | 21–17–62 |
| D | " | 220 | .314 | .189 | .684 | 1.187 | 50–18–32 | 1.01 | 792 | 26–16–58 |
| X | 17½ | 0 | .205 | .351 | 1.212 | 1.768 | 26–27–47 | 2.78 | 647 | 12–20–68 |
| A | " | 100 | .183 | .229 | .802 | 1.214 | 33–24–43 | 2.05 | 915 | 15–19–66 |
| B | " | 160 | .241 | .213 | .777 | 1.231 | 40–21–39 | 1.48 | 1248 | 20–17–63 |
| C | " | 160 | .229 | .206 | .785 | 1.220 | 39–21–40 | 1.56 | 922 | 19–17–64 |
| D | " | 220 | .273 | .183 | .647 | 1.103 | 47–19–34 | 1.10 | 873 | 25–16–59 |
| X | 20½ | 0 | .181 | .356 | 1.450 | 1.987 | 22–26–52 | 3.56 | 935 | 9–18–73 |
| A | " | 100 | .187 | .227 | 1.021 | 1.435 | 30–21–49 | 2.35 | 1098 | 13–16–71 |
| B | " | 160 | .208 | .186 | .933 | 1.327 | 35–18–47 | 1.87 | 1222 | 16–14–70 |
| C | " | 160 | .209 | .215 | 1.006 | 1.430 | 33–20–47 | 2.03 | 1350 | 15–15–70 |
| D | " | 220 | .258 | .175 | .873 | 1.306 | 38–23–39 | 1.60 | 1349 | 20–14–66 |

*Based on chemical equivalents.

### 9. *On the Composition of Leaves and Crusher Juices:*

(a) *Per cent nitrogen in the leaf-punch samples (Fig. 12) (Table 12 in Appendix):* Once again we find an excellent reflection of the nitrogen applications in the per cent nitrogen found in the leaf-punch samples. Statistically significant effects were measured at each preharvest, even though the actual percentage differences were quite small. The concentration in the leaf blades was somewhat lower during the early growth stages than that found in the plant crop.

The very low experimental error again associated with this measurement confirms our confidence in its reliability, and we have found its correlation with per cent N in the total dry weight and also with per cent N in the crusher juice to be highly significant. There still remains however its satisfactory interpretation before its utilization as a guide for nitrogen fertilization can be considered reliable.

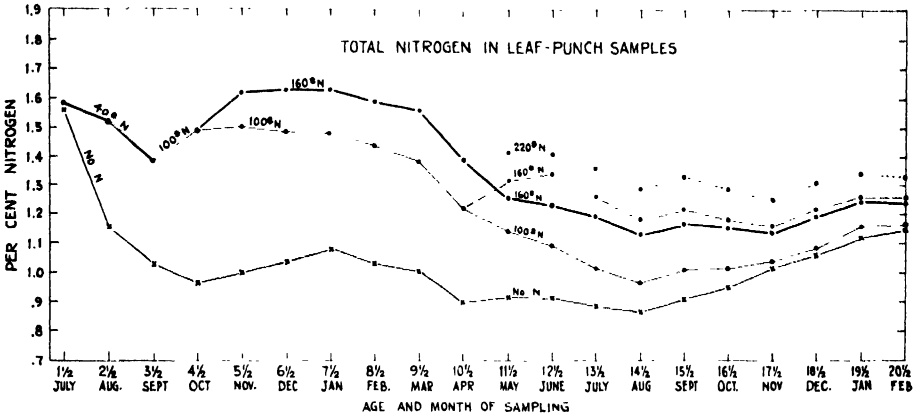

Fig. 12.

We have studied the data which show the relationship of the per cent N in the leaf-punch samples at 10½ months to the actual sugar yields when the field was finally harvested. Our objective still is to find a critical level for per cent N, especially just prior to that time when a deficiency, if identified, can be corrected by an additional application of fertilizer. In the plant crop, a concentration of 1.36 per cent nitrogen in the leaf-punch samples at 10½ months was indicated as too low, and a concentration of 1.46 per cent as fully adequate. In this ratoon it might be argued that although not proved significant, nevertheless because the final sugar yields from Treatments D and B were equal, and both were better than those from Treatments C and A respectively, both 1.38 per cent and 1.22 per cent N in the leaf-punch samples at 10½ months indicated a deficiency which an extra 60 pounds of N corrected. If this possibility is tentatively accepted, *i.e.*, that the 60-pound nitrogen applications in April did eventually result in similar and increased sugar yields, then we shall have to assume that Treatment C had an unnecessarily high N level prior to 10½ months and that that was an effect it received from the earlier 60-pound N increase over Treatment A in October. This may mean that perhaps it is not necessary to maintain a per cent N level in the leaf blades above 1.5 per cent at anytime, as there was certainly no visible indication during the early growth period of this crop that Treatment A was not making a satisfactory growth, or evidence that the production of total dry weight between Treatments A and C was different for at least 17½ months. Unfortunately the data do not furnish us with positive proof of an N percentage figure which may be construed as an adequate level in the leaf blades at 10½ months, unless we insist that since the treatment effects were not proved significant on the final yields, there was no real gain in sugar over that from Treatment A; in such case we would have to consider 1.22 per cent N in the leaf blades at 10½ months as adequately high; and this would be an amount somewhat less than we found to be inadequate in our plant crop! Clearly then we have not yet established the critical per cent N levels for leaf-punch samples.

(b) *Per cent nitrogen in the crusher juices (Fig. 13) (Table 13 in Appendix):* In this measurement too, we find a significant immediate effect from the different N applications at each preharvest, even though the coefficients of variation for this measurement were over 20 per cent. The setting up of a criterion of nitrogen deficiency or sufficiency for this analysis from this ratoon crop depends again upon whether one wishes to assume that there were or were not responses to the nitrogen applications above 100 pounds (Treatment A) in the final field yields. Statistically, such gains were not proved, but since this fact itself does not mean that such differences as were found might not have been proved gains if there had been still more replicates, we are perhaps not justified in dismissing either assumption; this makes the interpretation even more difficult! For instance at the critically indicated age of 10½ months we find .020 per cent N in the crusher juice of cane which had been supplied with 100 pounds of N (Treatment A) and if one assumes that B eventually outyielded A, then this .020 per cent N level was too low, for B received an extra 60 pounds of N immediately thereafter. With similar reasoning one would then be forced to conclude that the .033 per cent N in the juice of cane from Treatment C which had received 160 pounds of N was also inadequate, since D which subsequently received another 60 pounds of N eventually produced more sugar than C. Thus these results would be in disagreement with those from the plant crop wherein .030 per cent N at 10½ months was shown to be fully adequate to produce the maximum sugar yields at the final harvest.

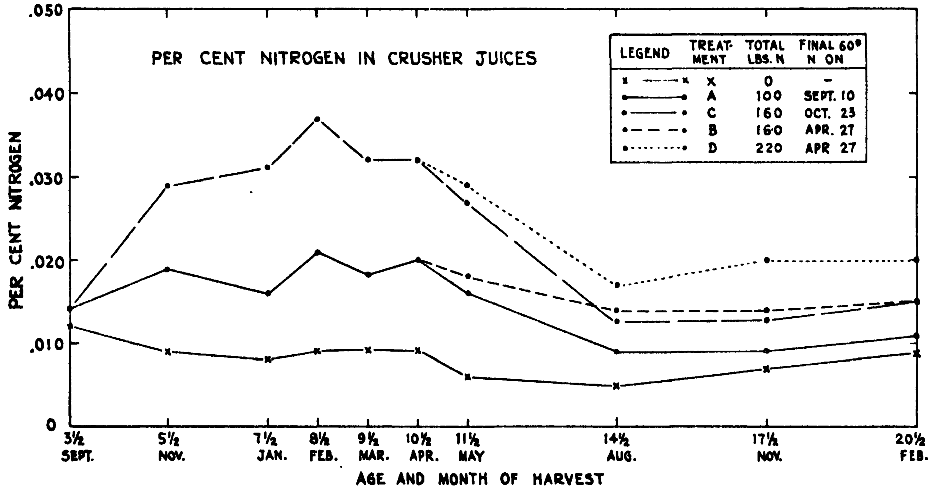

Fig. 13.

On the other hand if we accept the assumption that there was no gain for N applications greater than 100 pounds per acre (Treatment A) then we must conclude that .020 per cent N in the juice of cane at 10½ months was indicative of an adequate nitrogen status. This conclusion would be difficult to reconcile with the results from the plant crop which showed that a figure of .018 per cent was too low, *i.e.,* that additional nitrogen to cane with this low concentration did increase the final sugar yield!

## 10. *On the Yields per Acre:*

All interpretations which are based on yields per acre for the preharvest samples must be accepted as tentative because of the high experimental errors involved. Although the analysis of variance has been used to identify and separate the positional and treatment effects from the effects of error, the residual variations between the replicates are still large, and consequently very few treatment effects have been proved significant.

All figures given in the yield tables (except for Treatment X) are averages of 32 replicates at the first preharvest, of 16 replicates in the second to sixth preharvests, and of 8 thereafter. Averages from three X plots are listed but they were not used in the analysis of variance; thus the figure for the minimum difference required (M.d.r.) has no application to the yields from these X plots.

(a) *Reducing sugars, sucrose, and total sugars (Tables 14, 15, 16 in the Appendix):* In Table IV the data from the last four harvests are brought together for a study of the influence of nitrogen on the yields of reducing sugars, sucrose and total sugars. It will be seen that the higher nitrogen applications have given higher yields of reducing sugars, and the differences between Treatments A and D are highly significant at the last three harvests. Differences between C and B which both received 160 pounds of N, but with this total completed in October and the following April respectively, were not significant.

The effect of the nitrogen differentials on the yields of sucrose and of total sugars was quite similar. At 11½ months the high-nitrogen plots ("D") were the low producers, with very little difference between the other treatments. At 14½ months the "B" plots which had received their last 60 pounds of a 160-pound total application of N only four months previously, were ahead of the other treatments. At 17½ months, these same "B" plots were still in the lead in their sucrose and total sugar yields, with still very little difference between the other treatments. However, at the final preharvest at 20½ months, (1) the "A" plots (100 pounds N) had fallen down in their yields, (2) the "B" plots (160 pounds N, late) had not continued their previous rate of increase and were now a little behind the "C" plots (160 pounds N, early), and (3) the "D" plots had taken the lead.

TABLE IV

SUGARS IN TOTAL DRY WEIGHT—TONS PER ACRE

| Treatment | Total lbs. N applied by April | Last 60 lbs. N applied | May harvest at 11½ mos. Tons per acre | | | Aug. harvest at 14½ mos. Tons per acre | | |
|---|---|---|---|---|---|---|---|---|
| | | | Red. sugar | Sucrose | Total sugars | Red. sugar | Sucrose | Total sugars |
| A...... | 100 | Sept. | .43 | 10.35 | 11.32 | .83 | 11.37 | 12.80 |
| B...... | 160 | Apr. | .57 | 10.60 | 11.73 | 1.71 | 13.30 | 15.71 |
| C...... | 160 | Oct. | .74 | 10.02 | 11.29 | 1.37 | 11.44 | 13.40 |
| D...... | 220 | Apr. | .78 | 8.75 | 9.99 | 1.99 | 11.75 | 14.36 |

| | Nov. harvest at 17½ mos. Tons per acre | | | Feb. harvest at 20½ mos. Tons per acre | | |
|---|---|---|---|---|---|---|
| | Red. sugar | Sucrose | Total sugars | Red. sugar | Sucrose | Total sugars |
| A........................ | .87 | 15.33 | 17.01 | .49 | 17.38 | 18.79 |
| B........................ | 1.92 | 20.26 | 22.77 | .90 | 21.31 | 23.33 |
| C........................ | 1.36 | 14.98 | 16.90 | .86 | 22.03 | 24.04 |
| D........................ | 2.20 | 14.96 | 17.63 | 1.65 | 22.25 | 25.07 |

(b) *Millable cane and recoverable sugar (Fig. 14) (Tables 17 and 18 in Appendix):* All yields that we have reported from the successive preharvests have been

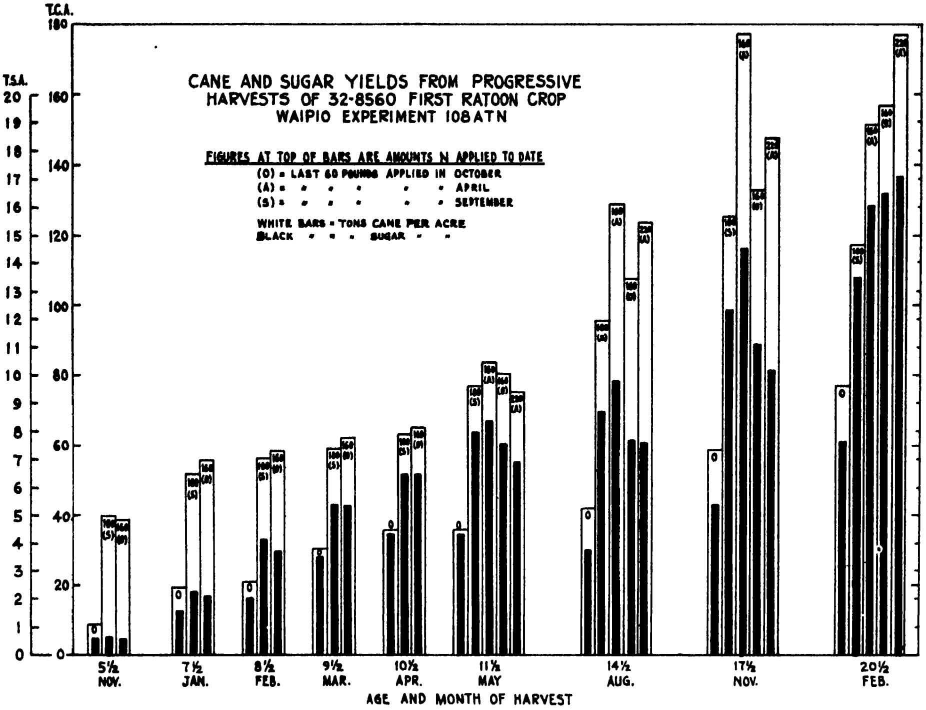

Fig. 14.

calculated on their actual net area basis of 25 square feet per plot; thus they will be found somewhat higher than respective field yields which would be calculated on gross acreage.

Our chief interest in these commercial yields rests in those from the last four harvests. At 11½ months the optimum sugar yield came from Treatment A which had received only 100 pounds N. At 14½ months and also at 17½ months there appears to be more sugar from Treatment B (160 pounds N—late) than from Treatment A (100 pounds N); but the increased amounts of cane that would have to be harvested and milled to get the extra sugar would indicate that Treatment A may still be the most profitable. However, Treatment C (160 pounds N—early) has not benefited by the extra 60 pounds of nitrogen it had received over Treatment A in October.

It seems logical to feel that the 220-pound application for Treatment D was excessive for cane harvested at 14½ or 17½ months, for there is nothing to suggest its superior effect on yield over the other plots that received nitrogen, but at the next harvest at 20½ months, the recoverable sugar from Treatment D had made a remarkable increase. Differences between treatments at 20½ months would seem to indicate that Treatment A (100 pounds) had now fallen behind the other treatments in sugar yields and that the 160 and 220 pounds N treatments were then about equal.

Table V has been prepared to show the increases and decreases made during successive growth periods. The variation between the treatments during the different growth stages needs careful study and rationalization. Average monthly gains in yields of cane were highest during Periods 4 and 5 while the crop was 11½ to 17½ months old. For sugar, the best monthly gains were made between 17½ and

20½ months and between 8½ and 11½ months. In the highly vegetative growth period between 11½ and 14½ months the increase in sugar was quite small.

Treatment B showed a remarkable spurt in cane yield after it was fertilized in April and made large increases during both Periods 4 and 5, but during the sixth growth period while it was being dried off, this cane appears to have suffered an enormous loss in yield. On the other hand Treatment C which had received its full 160-pound application of nitrogen six months earlier than Treatment B, made very consistent gains in millable cane yields throughout its last 12 months of growth and not only did not suffer from drying off but actually piled up a considerable increase in sugar during Period 6.

The large increase in T.C.A. made by Treatment D following the April fertilization was similar to that of Treatment B, but it did not continue through Period 5, nor was there any loss during drying off. In fact the cane and especially the sugar yield from Treatment D showed the greatest increase during this last Period 6.

### TABLE V

### AVERAGE INCREASES OR DECREASES IN YIELDS OF T.C.A. AND T.S.A.

| Growth period | No. of months | Months | Age of crop (months) | T.C.A. (net area) X | A | B | C | D | Avg. per month for all 5 treatments |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5½ | May–Nov. | 0–5½ | + 9.6 | +37.1 | +42.9 | +38.0 | +39.8 | +6.7 |
| 2 | 3 | Nov.–Feb. | 5½–8½ | +11.8 | $\overline{+16.0}$ | $\overline{+18.8}$ | $\overline{+19.4}$ | $\overline{+20.0}$ | +5.7 |
| 3 | 3 | Feb.–May | 8½–11½ | +15.7 | +24.5 | +21.8 | +23.5 | +15.8 | +6.8 |
| 4 | 3 | May–Aug. | 11½–14½ | + 5.3 | +18.2 | $\overline{+45.6}$ | +26.7 | $\overline{+47.8}$ | +9.6 |
| 5 | 3 | Aug.–Nov. | 14½–17½ | +16.5 | +29.4 | +48.2 | +25.4 | +23.5 | +9.5 |
| 6 | 3 | Nov.–Feb. | 17½–20½ | +14.5 | — 7.7 | —25.8 | +24.2 | +29.6 | +2.3 |
| Period | | | | T.S.A. (net area) X | A | B | C | D | |
| 1 | | | | + .51 | + .55 | + .77 | + .56 | + .59 | + .12 |
| 2 | | | | +1.58 | $\overline{+3.20}$ | $\overline{+3.78}$ | $\overline{+3.03}$ | $\overline{+3.40}$ | +1.00 |
| 3 | | | | +2.24 | +4.23 | +3.70 | +4.01 | +3.05 | +1.15 |
| 4 | | | | — .66 | + .68 | $\overline{+1.46}$ | + .10 | $\overline{+ .56}$ | + .14 |
| 5 | | | | +1.66 | +3.65 | +4.83 | +3.39 | +2.54 | +1.07 |
| 6 | | | | +2.37 | +1.23 | +1.60 | +5.40 | +6.91 | +1.17 |

*Note:* The horizontal bar (____) in the columns of Table V indicates that a nitrogen fertilizer application was made during the previous growth period.

### TABLE VI

### TONS SUGAR PER ACRE PER MONTH

| Treatment | Total lbs. N applied by April | Last 60 lbs. N applied | Tons sugar per acre per month May at 11½ mos. | August at 14½ mos. | November at 17½ mos. | February at 20½ mos. |
|---|---|---|---|---|---|---|
| A | 100 | September | .69 | .60 | .70 | .66 |
| B | 160 | April | .72 | .67 | .83 | .79 |
| C | 160 | October | .66 | .53 | .63 | .80 |
| D | 220 | April | .61 | .52 | .58 | .83 |

On the basis of sugar-per-acre-per-month we have the figures in Table VI. At 11½, 14½ and 17½ months, the highest rate has come from Treatment B (160 pounds N—late), with the low rate from Treatment D (220 pounds). At 20½ months, Treatment A (100 pounds) has fallen behind the more adequately fertilized cane from the other three treatments.

(c) *Relation between recoverable sugar and total sucrose (Table VII):* The effects of the different amounts of nitrogen on the proportion of recoverable sugar that was secured from the total sucrose made by the ratoon crop are shown in Table VII.

### TABLE VII
### RATIO OF T.S.A. TO TOTAL TONS SUCROSE

| | At 5½ mos. | 7½ | 8½ | 9½ | 10½ | 11½ | 14½ | 17½ | 20½ |
|---|---|---|---|---|---|---|---|---|---|
| X | .63 | .74 | .89 | .90 | .87 | .84 | .86 | .79 | .74 |
| A | .30 | .55 | .80 | .79 | .80 | .77 | .76 | .80 | .80 |
| B | ... | ... | ... | ... | ... | .78 | .73 | .71 | .76 |
| C | .31 | .50 | .72 | .76 | .78 | .76 | .67 | .74 | .75 |
| D | ... | ... | ... | ... | ... | .80 | .65 | .68 | .76 |

When only 100 pounds of N was applied (Treatment A) this ratio was maintained after 7½ months at fairly close to 80 per cent, with only slightly lower recoveries at 11½ and 14½ months. From Treatment C (160 pounds N—early) this same ratio was never above 78 per cent and at 14½ months was down as low as 67 per cent. Treatment B (160 pounds N—late) reached its lowest ratio of .71 at 17½ months. Treatment D (220 pounds N) hit the low point of only 65 per cent at 14½ months and was still low (.68) three months later, but at the final harvest, 75-76 per cent of the total sucrose made by Treatments B, C, and D was then recoverable sugar.

11. *On Cane Quality (Fig. 15) (Table 19 in Appendix):*

The effects from additional increments of nitrogen fertilizer on cane quality are quite definite and similar to what has often been found to be true, *i.e.*, (1) each increment results in fewer pounds of recoverable sugar per 100 pounds of cane milled, and (2) there is little difference in the effect on quality from a difference in the time of application of the same total amount.

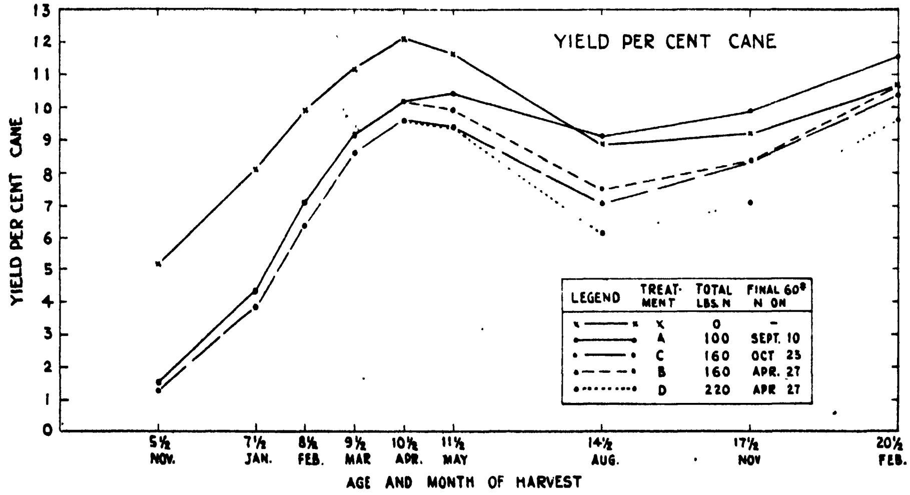

Fig. 15.

Regardless of nitrogen applied there were apparently two high peaks in yield per cent cane. One of these was reached at the early age of 10½-11½ months in April-May but immediately thereafter the cane quality dropped and was low at 14½ months in August. For the six months after this age, however, there was a steady improvement. This verifies a similar condition found at 14½ months in the plant crop, which age was, however, reached in October, and so it appears that it is largely an age effect. If true, then we would do well to avoid harvesting 32-8560 cane at about 14½ months at any season of the year, in order to take full advantage of the probable improvement in quality and large increase in recoverable sugar that the subsequent six months should give us.

### 12. *On Tonnage of Cane Tops:*

As was to be expected, the increased nitrogen applications produced larger yields of cane tops. The averaged amounts were generally highest at 14½ months and in this respect they resembled the results from the fertilized plots of the plant crop. The lower amounts from the final harvest are partly the influence of a deliberate attempt to reduce the amount of tops by drying off the field; apparently this was not done quite as completely on this ratoon as on the plant crop.

AVERAGE TONS PER ACRE OF CANE TOPS (TREATMENTS A, B, C, AND D)

| Crop | At 5½ mos. | At 8½ mos. | At 11½ mos. | At 14½ mos. | At 17½ mos. | At 20½ mos. |
|---|---|---|---|---|---|---|
| First ratoon | 17.4 | 13.4 | 19.4 | 21.0 | 19.2 | 16.1 |
| Plant | 18.1 | 16.2 | 20.7 | 21.5 | 20.2 | 14.0 |

### 13. *On the Recovery of Nutrients in the Total Dry Weight*:*

(a) *Nitrogen (Fig. 16) (Table 20 in Appendix):* In this crop it was found that the cane in the no-N plots was not able to secure as much nitrogen as it had taken up in the previous crop. We had suspected that this might be true from our observations of earlier leaf symptoms of nitrogen deficiency and the lower amounts of nitrogen in the monthly soil samples. The fact, however, that this non-fertilized cane did find an additional amount of nitrogen later in its growth period, is good evidence that the soil had made a late nitrogen contribution.

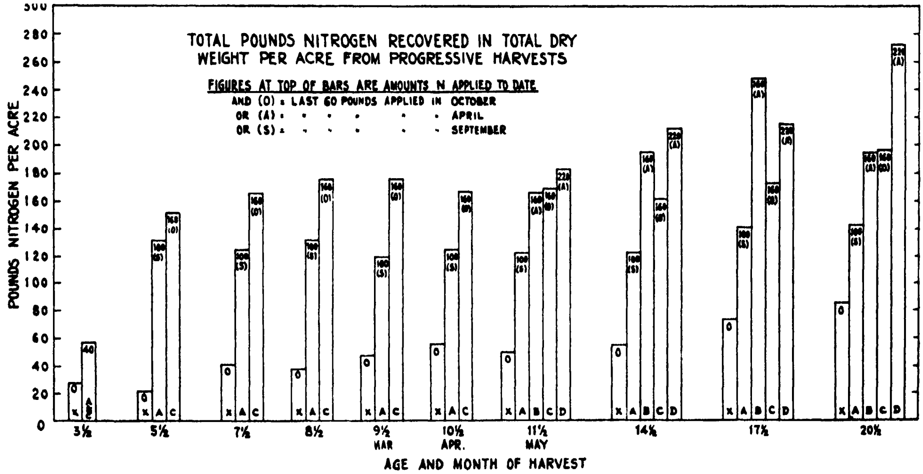

Fig. 16.

At 3½ months the fertilized cane had picked up only 58 pounds of nitrogen per acre, an amount quite comparable with that found in the plant crop (53 pounds) at the same age from a similar nitrogen fertilizer application, even though this ratoon had made twice as much total dry weight by this age. Approximately half of this amount could have come from the soil's natural supplies and the other half from the 40-pound N application which had been made at the age of five weeks.

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* Except trash and roots.

The fastest uptake of the applied nitrogen by this ratoon occurred between 3½ and 5½ months, and was especially noted following the 60-pound nitrogen applications in September. After the fall (Sept.-Oct.) applications, further increases in nitrogen recovery were very moderate. The April fertilization for Treatment B which then gave it a 160-pound total application was reflected in an immediate increase in nitrogen recovery, but the extra 60-pound April application for Treatment D to bring its total N to 220 pounds was not as quickly found in its crop. On the whole the amounts of nitrogen that were found in the successive harvests were considerably lower than the corresponding recoveries from the plant crop.

(b) *Phosphate and Potash (Fig. 17) (Tables 21 and 22 in Appendix):* The only significant effects from nitrogen applications upon the total recovery of phos-

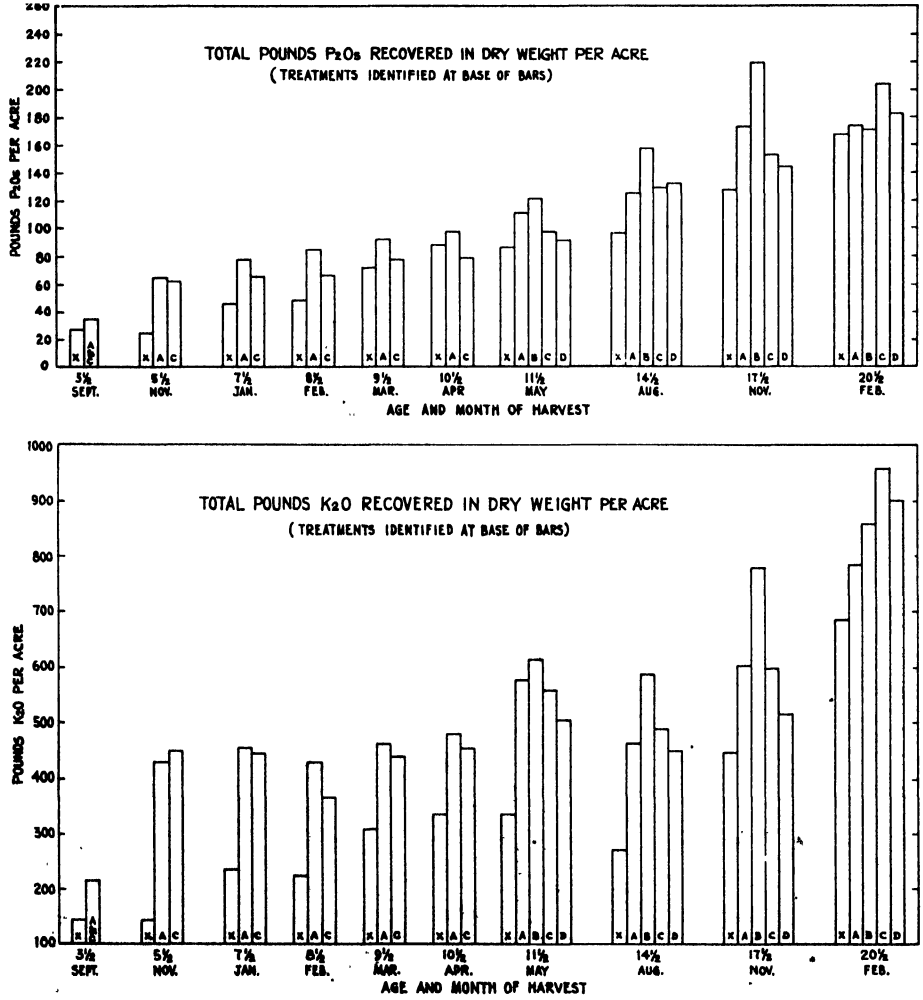

Fig. 17.

phate were found in the first-year harvests where slightly less phosphate was recovered from Treatment C than from Treatment A in spite of the fact that total dry weights from these two nitrogen treatments were very much alike. The actual amounts of phosphate recovered in the ratoon crops harvested were higher than from the plant crops, but were still not much over 100 pounds per acre until the crop entered its second year of growth. The ultimate amounts absorbed (about 180 to 200 pounds per acre) were more likely an effect of the crop's age than of its nitrogen differentials. The best treatments (B and D) took up about one pound of P205 for each ton of millable cane they produced.

The differences in total potash found in the dry weights were never proved to be a significant effect of the nitrogen treatments. The total amount in the crop at 3½ months had doubled itself at 5½ months, thus following a corresponding increase in the total dry weight. However, during the subsequent five months, there was little further increase in the amount of potash recovered although the dry weight was again doubled during this period. The maximum amounts in the crop at the final harvest were again large (in the neighborhood of 800 to 900 pounds per acre) and this fact cannot help but impress us with a realization of the heavy draft that cane crops make upon potash which is available to them.

Approximately 5 to 5½ pounds of potash had been taken up by this 32-8560 crop at 20½ months to produce each ton of millable cane.

## Nitrogen Correlations

*Between per cent nitrogen in leaf-punch samples and per cent nitrogen in (a) total dry weight and (b) crusher juice:*

Generally speaking, our guidance for nitrogen fertilization will be sought from those analyses which are made while the crop is between six and 12 months old. In the present study we have looked for this guidance in the percentage of nitrogen found (1) in leaf-punch samples taken from the young active green-leaf blades, (2) in the total dry weight of samples which truly represent the complete crop as harvested, and (3) in the crusher juice samples from all living stalks with millable cane.

We have previously shown that each of these three samples has quite definitely reflected the different nitrogen levels which the treatments created. But in Table I we noted that the leaf-punch samples had much the lowest coefficients of variation, so it can be assumed that the leaf blades sampled are extremely homogeneous and would be the most dependable as a source of samples for nitrogen analysis.

The relationship between the percentages of nitrogen found in the leaf-punch samples and the corresponding composition of both total dry weight and crusher juices is shown in Table VIII. The correlation coefficients (r) are positive and highly significant, much more so than were found for the same analyses made from the plant crop.

TABLE VIII

CORRELATION BETWEEN NITROGEN ANALYSES

| Age (mos.) | Average 32 plots* % N | | | Correlation (r) between % N in | |
|---|---|---|---|---|---|
| | In leaf | In dry wt. | In juice | Leaf and dry wt. | Leaf and juice |
| 7½ | 1.55 | .521 | .024 | .82∓.06 | .85∓.05 |
| 8½ | 1.51 | .452 | .029 | .81∓.06 | .71∓.09 |
| 9½ | 1.47 | .380 | .025 | .81∓.06 | .67∓.10 |
| 10½ | 1.30 | .330 | .026 | .84∓.05 | .64∓.10 |
| 11½ | 1.28 | .311 | .023 | .77∓.07 | .48∓.14 |

*The "no-N" plots are not included.

## WEATHER RELATIONSHIPS

In Table IX we have summarized the basic weather data during six growth periods, each of three months duration except the first one. With this we have included the associated yield data from Treatment B which has again been assumed to be the most efficient sugar producer. From Table IX we have then prepared Table X to show the relative effectiveness of the weather measurements on the yields. The data are not easy for us to interpret but we record them in the hopes that someone may be able to rationalize them. They do, however, indicate again that sunlight energy (as well as hours of sunshine and day-degrees) has a very different effect on yields in the different crop-age periods. To cite just one example, we note that the tons commercial sugar per 1000 gram calories of sunlight energy received was only .026 for Period 4 between May and August when the crop was 11½ to 14½ months old, whereas for the subsequent three months it was four times this amount.

### TABLE IX
### BASIC YIELD AND WEATHER DATA

| Growth period | Dates | Crop age (mos.) | Increase in yields—tons/acre. Average of 8 "B" plots: Green wt. | Dry wt. | Tot. sugars | T.C.A. | T.S.A. |
|---|---|---|---|---|---|---|---|
| 1 | 5/25–11/16 | 0–5½ | 57.01 | 10.88 | 3.13 | 40.0 | .66 |
| 2 | 11/17–2/15 | 5½–8½ | 13.92 | 6.30 | 3.09 | 17.4 | 3.49 |
| 3 | 2/16–5/17 | 8½–11½ | 33.02 | 10.79 | 5.51 | 26.1 | 4.10 |
| 4 | 5/18–8/16 | 11½–14½ | 49.42 | 10.61 | 3.98 | 45.6 | 1.46 |
| 5 | 8/17–11/15 | 14½–17½ | 48.78 | 12.94 | 7.06 | 48.2 | 4.83 |
| 6 | 11/16–2/14 | 17½–20½ | —34.99 | —5.02 | .56 | —25.8 | 1.60 |

### WEATHER MEASUREMENTS

| Growth period | Gram calories | Hours of sunshine | Day-degrees | Avg. temperature Min. | Avg. temperature Max. | Range in temperature | Avg. wind velocity m.p.h. |
|---|---|---|---|---|---|---|---|
| 1 | 96,469 | 1,299 | 2850 | 67.6° | 86.4° | 18.8° | 6.0 |
| 2 | 32,672 | 500* | 1089 | 64.3 | 82.0 | 17.7 | 4.7 |
| 3 | 48,995 | 630* | 1129 | 62.7 | 82.4 | 19.7 | 5.4 |
| 4 | 56,545 | 658* | 1602 | 68.1 | 87.5 | 19.4 | 6.0 |
| 5 | 45,202 | 602* | 1720 | 66.7 | 88.7 | 22.0 | 5.1 |
| 6 | 33,101 | 504* | 1248 | 62.0 | 84.0 | 22.0 | 4.7 |
| Total | 312,984 | 4,193* | 9638 | | | | |

*Instrument out of order; estimated from blueprint recorder relationship with Friez instrument.

### TABLE X
### SUNLIGHT AND TEMPERATURE UTILIZATION (BY TREATMENT B)

| Growth period | Tons tot. green wt. per acre | | | Tons tot. dry wt. per acre | | | Tons tot. sugars per acre | | |
|---|---|---|---|---|---|---|---|---|---|
| | Per 1000 gms. cal. | Per 100 hrs. sun | Per 1000 day-deg. | Per 1000 gms. cal. | Per 100 hrs. sun | Per 1000 day-deg. | Per 1000 gms. cal. | Per 100 hrs. sun | Per 1000 day-deg. |
| 1 | .591 | 4.389 | 20.004 | .113 | .838 | 3.818 | .032 | .241 | 1.098 |
| 2 | .426 | 2.784* | 12.782 | .193 | 1.260* | 5.785 | .095 | .618* | 2.837 |
| 3 | .674 | 5.241* | 29.247 | .220 | 1.713* | 9.557 | .112 | .874* | 4.880 |
| 4 | .874 | 7.511 | 30.849 | .188 | 1.612* | 6.623 | .070 | .605* | 2.484 |
| 5 | 1.079 | 8.102* | 28.360 | .286 | 2.149* | 7.523 | .156 | 1.173* | 4.105 |
| 6 | (loss) | (loss) | (loss) | (loss) | (loss) | (loss) | .017 | .011* | .449 |

| Growth period | Tons millable cane per acre | | | Tons comml. sugars per acre | | |
|---|---|---|---|---|---|---|
| | Per 1000 gms. cal. | Per 100 hrs. sun | Per 1000 day-deg. | Per 1000 gms. cal. | Per 100 hrs. sun | Per 1000 day-deg. |
| 1 | .415 | 3.079 | 14.035 | .007 | .051 | .232 |
| 2 | .533 | 3.480* | 15.978 | .107 | .698* | 3.205 |
| 3 | .533 | 4.142* | 23.118 | .084 | .651* | 3.632 |
| 4 | .806 | 6.930* | 28.464 | .026 | .222* | .911 |
| 5 | 1.066 | 8.007* | 28.023 | .107 | .802* | 2.808 |
| 6 | (loss) | (loss) | (loss) | .048 | .032* | 1.282 |

*Based on corrected estimate of hours of sunshine measured with blueprint recorder.

## Other Interesting Relationships

1. *Ratio of Per Cent Total Sugars to Per Cent N in Total Dry Weight:*

In the September harvest at 3½ months we found that the 32 plots, which had all received 40 pounds of nitrogen in July, had a total sugar concentration that was 36 times the percentage of nitrogen. At the November harvest at 5½ months and at the four subsequent harvests, the effect of a difference in the amount of nitrogen applied had definitely made its impression on this per cent sugar/per cent N ratio. At 10½ months in April, a ratio of 145 parts of total sugars to one part of nitrogen was found in cane which had received only 100 pounds of nitrogen; the corresponding ratio from cane which had already been supplied with 160 pounds of N was 111 to 1 at this same harvest. Whether or not this larger 145-to-1 ratio represents an undesirably high carbohydrate-nitrogen status at this age depends upon our interpretation of the final yields; if we assume that Treatment B outyielded Treatment A (although this was not proved significant), then this ratio was too wide and the extra 60-pound nitrogen application was called for. Then by similar reasoning we would have to consider that Treatment D was better than C, and from this assumption conclude that the lower 111-to-1 ratio was also too high and needed lowering by the application of more nitrogen. Such reasoning will then need reconciliation with the finding that in the previous crop a ratio of 124 to 1 was proved to be too wide but one of 95 to 1 was apparently quite satisfactory.

RATIO OF PER CENT TOTAL SUGARS TO PER CENT N IN TOTAL DRY WEIGHT

| Treatment | No. of plots. | November 5½ mos. | January 7½ mos. | February 8½ mos. | March 9½ mos. | April 10½ mos. | (Previous crop in June at 10½ mos.) |
|---|---|---|---|---|---|---|---|
| A+B | 16 | 46.0 | 82.1 | 93.1 | 126.7 | 144.8 | (124.0) |
| C+D | 16 | 35.2 | 65.3 | 71.0 | 91.3 | 111.4 | (95.1) |

2. *Ratio of Pounds of Nitrogen per Acre Recovered in Crop to Tons Millable Cane Harvested:*

The number of pounds of nitrogen taken up by a crop for each ton of millable cane obtained at the last three harvests is shown below and the figures are not greatly different from results found from the plant crop. (Roots and dry trash are not included in these data.) Apparently only about 1.5 pounds of N will be needed to produce a ton of millable 32-8560 cane if its usage gets full efficiency.

| | Pounds N per ton cane | | |
|---|---|---|---|
| Treatment | 14½ mos. | 17½ mos. | 20½ mos. |
| X | 1.3 | 1.3 | 1.2 |
| A | 1.3 | 1.1 | 1.2 |
| B | 1.5 | 1.5 | 1.3 |
| C | 1.5 | 1.3 | 1.2 |
| D | 1.7 | 1.4 | 1.5 |

3. *Ratio of Per Cent Reducing Sugars to Per Cent Sucrose:*

Small but increased ratios of reducing sugars to sucrose were found from each additional nitrogen application. This was especially notable at the August harvest at 14½ months.

RATIO OF PER CENT REDUCING SUGARS TO PER CENT SUCROSE

| Treatment | Harvested in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sept. | Nov. | Jan. | Feb. | Mar. | Apr. | May | Aug. | Nov. | Feb. |
| X | .33 | .13 | .06 | .04 | .02 | .03 | .03 | .08 | .05 | .02 |
| A | .65 | .39 | .20 | .14 | .06 | .05 | .04 | .07 | .06 | .03 |
| B | .. | .. | .. | .. | .. | .. | .05 | .13 | .09 | .04 |
| C | .. | .45 | .23 | .15 | .07 | .06 | .07 | .12 | .09 | .04 |
| D | .. | .. | .. | .. | .. | .. | .08 | .17 | .15 | .07 |

### 4. *Ratio of Total Sugars to Total Dry Weight (Tons per acre):*

The different nitrogen treatments had little if any effect on the ratios of total sugars to total dry weight. The ratio for Treatments A and C throughout the crop, and for B and A and for D and C after the April fertilizations had been applied to B and to D are almost identical, even though each of these pairs of treatments contained a nitrogen differential of 60 pounds per acre. The ratios have a great deal of similarity to those from the plant crop, and again we find that the total sugars make up just about 50 per cent of the total dry weight at 20½ months regardless of differences in the nitrogen fertilization of the cane crop which has been grown.

RATIO OF TOTAL SUGARS TO TOTAL DRY WEIGHT

| Treatment | Harvested in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sept. | Nov. | Jan. | Feb. | Mar. | Apr. | May | Aug. | Nov. | Feb. |
| X | .17 | .30 | .38 | .49 | .38 | .39 | .41 | .36 | .41 | .48 |
| A | .19 | .29 | .38 | .36 | .40 | .41 | .44 | .43 | .45 | .50 |
| B | .. | .. | .. | .. | .. | .. | .42 | .41 | .44 | .50 |
| C | .. | .27 | .38 | .37 | .40 | .42 | .43 | .42 | .45 | .50 |
| D | .. | .. | .. | .. | .. | .. | .41 | .42 | .45 | .48 |

### 5. *Ratio of Tons Reducing Sugars to Total Dry Weight:*

We do, however, find again that the nitrogen treatments have increased the ratio of the tonnage of reducing sugars to the total dry weight. This is apparent from the A vs. C, A vs. B, and C vs. D comparisons which have had a 60-pound N differential.

RATIO OF TONS REDUCING SUGARS TO TOTAL DRY WEIGHT

| Treatment | Harvested in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sept. | Nov. | Jan. | Feb. | Mar. | Apr. | May | Aug. | Nov. | Feb. |
| X | .037 | .032 | .021 | .012 | .007 | .012 | .012 | .027 | .019 | .010 |
| A | .073 | .079 | .058 | .040 | .021 | .018 | .017 | .028 | .023 | .013 |
| B | ... | ... | ... | ... | ... | ... | .020 | .044 | .037 | .019 |
| C | ... | .078 | .066 | .044 | .024 | .022 | .028 | .043 | .036 | .018 |
| D | ... | ... | ... | ... | ... | ... | .032 | .058 | .056 | .032 |

### 6. *Ratio of Tons Sucrose to Tons Dry Weight:*

The effect of nitrogen differentials upon the ratio of sucrose to dry weight appears to be very slight, all differences being very small ones. As was found in the plant crop, again about 46 per cent of the total dry weight was sucrose.

RATIO OF TONS SUCROSE TO TOTAL DRY WEIGHT

| Treatment | Harvested in | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sept. | Nov. | Jan. | Feb. | Mar. | Apr. | May | Aug. | Nov. | Feb. |
| X | .12 | .26 | .34 | .32 | .35 | .36 | .38 | .32 | .37 | .45 |
| A | .11 | .20 | .30 | .30 | .36 | .38 | .40 | .38 | .40 | .46 |
| B | .. | .. | .. | .. | .. | .. | .38 | .35 | .39 | .46 |
| C | .. | .18 | .30 | .31 | .36 | .37 | .39 | .36 | .40 | .46 |
| D | .. | .. | .. | .. | .. | .. | .36 | .34 | .38 | .43 |

### 7. *Ratio of Commercial Sugar to Total Dry Weight:*

This ratio of commercial sugar to total dry weight which is tabulated hereafter for the last four harvests tends to show slightly lower amounts associated with the increased nitrogen applications. Of general interest is the fact that only approximately 35 per cent of the total dry weight at the final harvest was calculated as commercial sugar, whereas we have previously shown about 46 per cent to be sucrose and 50 per cent to be total sugars.

RATIO OF TONS COMMERCIAL SUGARS TO TOTAL DRY WEIGHT

| Treatment | Harvested in | | | |
|---|---|---|---|---|
| | May | August | November | February |
| X | .32 | .27 | .29 | .33 |
| A | .31 | .29 | .32 | .36 |
| B | .29 | .25 | .28 | .35 |
| C | .29 | .24 | .30 | .35 |
| D | .29 | .22 | .26 | .33 |

## DISCUSSION

Most of the measurements obtained from the first ratoon crop in this study have already been adequately discussed, and to those who have critically examined the tables and graphs it is quite apparent that we have not yet attained our main objective, *i.e.*, the establishment of a critical nitrogen index. Part of our difficulty is due to the fact that in this ratoon our field experiment did not establish a proved effect for the four different nitrogen applications, *i.e.*, such differences in sugar yields as were found between these treatments could have been due to chance alone. Thus even though our eight replications of treatments resulted in a creditably low experimental error, we did not actually prove any gains in sugar (T.S.A.) for any nitrogen applications greater than 100 pounds per acre, as the following analysis of variance and yield summary will substantiate.

WAIPIO EXPERIMENT 108 ATN—FIRST RATOON—HARVESTED AT 22 MONTHS

| Source | Degrees of freedom | Analysis of variance. Mean squares | | |
|---|---|---|---|---|
| | | In T.C.A. | In Y%C | For T.S.A. |
| Blocks | 7 | 399.08* | 4.59** | 5.76** |
| Treatments | 3 | 610.43** | 3.07* | .91(ns) |
| Error | 21 | 113.93 | .86 | .70 |
| Coef. of variation | | 8.5% | 9.0% | 6.5% |

*Significant. **Highly significant. (ns) = not significant.

SUMMARY OF FIRST RATOON YIELDS (AVERAGES FOR 8 PLOTS)

Harvested March 16 - April 4, 1944, Age 22 Months

| Plot identity | Pounds N applied | | | | | Yields per acre (gross area) | | |
|---|---|---|---|---|---|---|---|---|
| | July | Sept. | Oct. | April | Total | Tons cane | Y%C | Tons sugar |
| A | 40 | 60 | 0 | 0 | 100 | 115.2 | 11.12 | 12.65 |
| B | 40 | 60 | 0 | 60 | 160 | 127.4 | 10.48 | 13.22 |
| C | 40 | 60 | 60 | 0 | 160 | 125.7 | 10.10 | 12.60 |
| D | 40 | 60 | 60 | 60 | 220 | 136.6 | 9.66 | 13.19 |
| Min. difference needed for significance | | | | | | 11.1 | .96 | (.87)ns |

Since we did measure a significant gain in T.S.A. for 160 pounds of N (Treatment B) over 100 pounds from the previous or plant crop,* and as it seems most unlikely that the first ratoon would make its optimum yield when cut at the same age, on less than 160 pounds, it is not altogether unreasonable to assume, at least tentatively, that Treatment B was again the optimum, and in much of the discussion which has preceded this, we have accepted this possibility.

Some of the more specific effects from the different applications of nitrogen have been pointed out. Thus we have again found that (1) the soil has contributed some of its nitrogen to the crop; (2) the heavier nitrogen fertilizer applications have resulted in greater yields of green weight, dry weight, and millable cane; (3) higher percentages of moisture, of reducing sugars, and of nitrogen in dry weight, leaf blades and crusher juice have come from the higher amounts of nitrogen; but (4) lower percentages of fiber, of sucrose, of phosphate and potash, and a lower yield per cent cane (poorer quality) have been the result of the increased nitrogen.

If we accept for the time being the opinion that Treatment B possibly did respond to its extra 60 pounds of N applied in April, then we can consider the following nitrogen levels in Treatment A of our 32-8560 cane crop at 10½ months, as indications of a nitrogen deficiency: (a) .29 per cent N in total dry weight, (b) 1.22 per cent N in the leaf-punch samples, and (c) .020 per cent N in the crusher juice. In the plant crop these deficiency levels were respectively .33, 1.36, and .018. Although these two sets of figures show a fair degree of similarity, we must not forget that we haven't yet estimated a reliable "sufficiency N level," and this will be a much more important one in the control of our sugar yields.

The study continues. The second ratoon crop is underway and the early preharvests are already being made.

## ACKNOWLEDGMENTS

Again it would have been impossible to make this study without the help of many staff members and their assistants. Hence we gratefully acknowledge the cooperation and the assistance supplied by all members of the several research laboratories and departments who have had a part in the large volume of work involved in an investigation of this nature.

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* For comparison, the yields from the plant crop harvest are given below:

PLANT CROP—YIELDS

Harvested May 5-17, 1942, Age 21½ Months

| Plot identity | Pounds N applied |  |  |  |  | Yields per acre (gross area) |  |  |
|---|---|---|---|---|---|---|---|---|
|  | Sept. | Nov. | March | June | Total | Tons cane | Y%C | Tons sugar |
| A.......... | 40 | 60 | 0 | 0 | 100 | 110.9 | 13.9 | 14.7 |
| B.......... | 40 | 60 | 0 | 60 | 160 | 120.0 | 13.2 | 15.7 |
| C.......... | 40 | 60 | 60 | 0 | 160 | 120.2 | 13.1 | 15.6 |
| D.......... | 40 | 60 | 60 | 60 | 220 | 122.7 | 12.7 | 15.5 |
| Min. difference needed for significance............ |  |  |  |  |  | ns | .67 | .56 |

# Appendix

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## CONTAINING SUMMARIES OF DATA AND STATISTICAL MEASUREMENTS THEREOF FROM WAIPIO EXPT. 108 ATN—FIRST RATOON CROPS

(Measurements from the 3 "X" Plots were not included in the statistical computations)

S.D. = Standard Deviation.
C.V. = Coefficient of Variation.
M.d.r. = Minimum difference required for significance between Treatments A, B, C, and D only.
ns = Treatment effect not significant.

### TABLE 1
### TOTAL GREEN WEIGHT—TONS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 15.97 | 14.62 | 26.94 | 27.88 | 39.31 | 47.33 | 47.48 | 53.10 | 70.93 | 83.09 |
| A | 28.44 | 57.01 | 66.69 | 70.93 | 73.52 | 79.71 | 94.85 | 112.71 | 141.84 | 130.49 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 103.95 | 153.37 | 202.15 | 167.16 |
| C | ..... | 56.29 | 71.46 | 71.75 | 78.21 | 83.73 | 100.84 | 127.68 | 150.09 | 172.58 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 95.22 | 145.67 | 165.23 | 195.97 |
| S.D. | 10.1 | 13.6 | 11.5 | 16.3 | 17.1 | 16.1 | 38.3 | 29.9 | 54.7 | 51.9 |
| C.V. | 35.5 | 24.1 | 16.7 | 22.9 | 22.5 | 19.7 | 38.8 | 22.1 | 33.2 | 31.2 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

### TABLE 2
### PER CENT TOPS IN TOTAL GREEN WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 54.41 | 34.97 | 26.77 | 23.39 | 21.93 | 22.07 | 22.21 | 20.22 | 17.50 | 11.93 |
| A | 50.56 | 30.62 | 22.12 | 19.18 | 19.68 | 19.27 | 18.21 | 15.05 | 11.54 | 10.06 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 19.88 | 15.97 | 12.43 | 9.50 |
| C | ..... | 30.92 | 21.59 | 18.40 | 20.02 | 20.36 | 19.90 | 15.87 | 11.38 | 9.10 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 20.59 | 15.25 | 11.14 | 10.00 |
| S.D. | 6.08 | 3.98 | 2.56 | 2.97 | 1.48 | 2.60 | 2.10 | 1.68 | 1.72 | 1.43 |
| C.V. | 12.0 | 12.9 | 11.7 | 15.8 | 7.5 | 13.1 | 10.7 | 10.8 | 14.8 | 14.7 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

### TABLE 3
### PER CENT MOISTURE IN TOTAL GREEN WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 78.17 | 78.96 | 76.53 | 74.00 | 72.35 | 70.47 | 71.42 | 74.60 | 74.08 | 71.88 |
| A | 79.61 | 80.89 | 79.52 | 75.88 | 74.25 | 72.47 | 72.48 | 73.29 | 73.16 | 71.40 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 73.16 | 74.94 | 74.57 | 72.07 |
| C | ..... | 81.56 | 80.06 | 76.15 | 74.87 | 73.60 | 74.21 | 75.00 | 74.96 | 72.47 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 74.54 | 76.44 | 76.17 | 73.31 |
| S.D. | 1.04 | .91 | 1.37 | 1.19 | 1.14 | 1.01 | 1.42 | 1.27 | 1.04 | 1.55 |
| C.V. | 1.3 | 1.1 | 1.7 | 1.6 | 1.5 | 1.4 | 1.9 | 1.7 | 1.4 | 2.1 |
| M.d.r. | ..... | .66 | ns | ns | ns | .75 | 1.48 | 1.31 | 1.08 | ns |

## TABLE 4

### PER CENT FIBER IN TOTAL GREEN WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 16.73 | 13.70 | 13.73 | 14.73 | 14.71 | 15.67 | 16.03 | 14.85 | 14.69 | 14.95 |
| A | 15.23 | 13.07 | 12.29 | 13.57 | 13.87 | 14.99 | 14.90 | 14.27 | 14.50 | 14.52 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 14.97 | 13.80 | 14.08 | 13.88 |
| C | ..... | 12.59 | 12.11 | 13.19 | 13.90 | 14.58 | 14.17 | 13.46 | 13.72 | 13.67 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 14.13 | 12.94 | 13.18 | 13.53 |
| S.D. | 1.05 | .71 | .56 | .94 | .91 | .93 | .94 | .62 | .76 | .85 |
| C.V. | 6.9 | 5.5 | 4.6 | 7.0 | 6.6 | 6.3 | 6.5 | 4.6 | 5.5 | 6.1 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | .64 | .79 | ns |

## TABLE 5

### TOTAL DRY WEIGHT—TONS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 3.50 | 3.11 | 6.32 | 7.23 | 10.84 | 13.98 | 13.60 | 13.47 | 18.22 | 23.53 |
| A | 5.73 | 10.88 | 13.68 | 17.18 | 18.97 | 21.92 | 25.93 | 30.06 | 37.93 | 37.72 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 27.97 | 38.58 | 51.52 | 46.50 |
| C | ..... | 10.46 | 14.32 | 17.20 | 19.78 | 22.19 | 26.03 | 31.96 | 37.57 | 47.76 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 24.22 | 34.53 | 39.35 | 52.36 |
| S.D. | 1.90 | 2.76 | 2.49 | 4.30 | 4.86 | 4.39 | 9.94 | 7.58 | 13.85 | 14.90 |
| C.V. | 33.2 | 25.9 | 17.8 | 25.0 | 25.1 | 19.9 | 38.2 | 22.4 | 33.3 | 32.3 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

## TABLE 6

### PER CENT REDUCING SUGARS IN TOTAL DRY WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 3.90 | 3.38 | 2.03 | 1.16 | .73 | 1.17 | 1.23 | 2.69 | 1.80 | 1.02 |
| A | 7.03 | 7.75 | 5.89 | 4.08 | 2.08 | 1.79 | 1.70 | 2.76 | 2.25 | 1.47 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 2.06 | 4.56 | 3.69 | 1.93 |
| C | ..... | 8.11 | 6.73 | 4.56 | 2.50 | 2.24 | 2.82 | 4.37 | 3.62 | 1.93 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 3.24 | 5.86 | 5.60 | 3.12 |
| S.D. | 1.19 | 1.32 | .88 | .77 | .70 | .51 | .77 | .80 | .81 | .82 |
| C.V. | 17.0 | 16.6 | 13.9 | 17.8 | 30.6 | 25.4 | 31.3 | 18.2 | 21.4 | 38.9 |
| M.d.r. | ..... | ns | .64 | ns | ns | .37 | .81 | .83 | .84 | .85 |

## TABLE 7

### PER CENT SUCROSE IN TOTAL DRY WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 11.88 | 25.13 | 34.33 | 32.51 | 35.76 | 36.35 | 37.24 | 32.15 | 37.36 | 45.35 |
| A | 10.82 | 19.66 | 30.19 | 30.15 | 36.05 | 37.69 | 39.66 | 37.95 | 40.62 | 46.39 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 37.60 | 34.35 | 39.67 | 45.86 |
| C | ..... | 17.92 | 29.71 | 30.43 | 35.99 | 37.37 | 38.60 | 35.67 | 39.81 | 46.16 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 36.31 | 34.01 | 38.17 | 42.78 |
| S.D. | 1.61 | 1.62 | 3.51 | 2.56 | 1.78 | 2.97 | 2.12 | 2.18 | 1.61 | 2.77 |
| C.V. | 14.9 | 8.6 | 11.7 | 8.6 | 4.9 | 7.9 | 5.6 | 6.1 | 4.1 | 6.1 |
| M.d.r. | ..... | 1.18 | ns | ns | ns | ns | 2.20 | 2.27 | 1.66 | ns |

## TABLE 8

## PER CENT TOTAL SUGARS IN TOTAL DRY WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 16.40 | 29.01 | 38.17 | 35.38 | 38.37 | 39.42 | 40.43 | 36.53 | 41.14 | 48.75 |
| A | 18.41 | 28.38 | 37.68 | 36.04 | 40.04 | 41.47 | 43.44 | 42.71 | 45.01 | 50.30 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 41.65 | 40.76 | 44.87 | 50.20 |
| C | ..... | 26.98 | 38.00 | 36.59 | 40.39 | 41.64 | 43.46 | 41.91 | 44.95 | 50.52 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 41.46 | 41.66 | 44.79 | 48.14 |
| S.D. | .75 | 2.19 | 3.64 | 2.54 | 1.97 | 3.01 | 2.19 | 2.09 | 2.86 | 2.74 |
| C.V. | 4.1 | 7.9 | 9.6 | 7.0 | 4.9 | 7.2 | 5.2 | 5.0 | 6.4 | 5.5 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

## TABLE 9

## PER CENT NITROGEN IN TOTAL DRY WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | .421 | .356 | .316 | .265 | .222 | .203 | .184 | .207 | .205 | .181 |
| A | .512 | .617 | .459 | .387 | .317 | .287 | .237 | .205 | .183 | .187 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | .301 | .256 | .241 | .208 |
| C | ..... | .731 | .583 | .516 | .443 | .374 | .329 | .255 | .229 | .209 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | .380 | .314 | .273 | .258 |
| S.D. | ,045 | .088 | .050 | .051 | .046 | .029 | .040 | .032 | .024 | .034 |
| C.V. | 8.8 | 13.1 | 9.6 | 11.3 | 12.1 | 8.8 | 12.9 | 12.5 | 10.4 | 15.8 |
| M.d.r. | ..... | .064 | .037 | .037 | .034 | .021 | .042 | .033 | .025 | .035 |

## TABLE 10

## PER CENT $P_2O_5$ IN TOTAL DRY WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | .41 | .41 | .36 | .33 | .329 | .318 | .327 | .359 | .351 | .356 |
| A | .31 | .31 | .29 | .25 | .243 | .221 | .210 | .209 | .229 | .227 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | .217 | .207 | .213 | .186 |
| C | ..... | .30 | .23 | .20 | .196 | .179 | .186 | .202 | .206 | .215 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | .185 | .189 | .183 | .175 |
| S.D. | .04 | .028 | .03 | .03 | .024 | .017 | .031 | .021 | .021 | .027 |
| C.V. | 12.9 | 9.3 | 11.5 | 13.6 | 10.9 | 8.5 | 15.5 | 10.4 | 10.1 | 13.4 |
| M.d.r. | ..... | ns | .02 | .02 | .018 | .012 | ns | ns | .021 | .028 |

## TABLE 11

## PER CENT $K_2O$ IN TOTAL DRY WEIGHT

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 2.04 | 2.27 | 1.85 | 1.53 | 1.42 | 1.188 | 1.207 | 1.024 | 1.212 | 1.450 |
| A | 1.91 | 1.99 | 1.66 | 1.26 | 1.24 | 1.075 | 1.104 | .788 | .803 | 1.021 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 1.130 | .759 | .777 | .933 |
| C | ..... | 2.17 | 1.55 | 1.09 | 1.14 | 1.037 | 1.064 | .757 | .785 | 1.006 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 1.051 | .684 | .647 | .873 |
| S.D. | .26 | .21 | .25 | .23 | .18 | .174 | .170 | .104 | .074 | .131 |
| C.V. | 13.6 | 10.1 | 15.6 | 19.5 | 15.1 | 16.5 | 15.6 | 13.9 | 9.8 | 13.7 |
| M.d.r. | ..... | .16 | ns | .17 | ns | ns | ns | ns | .077 | .136 |

## TABLE 12

## PER CENT NITROGEN IN LEAF-PUNCH SAMPLES

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 1.03 | 1.00 | 1.08 | 1.04 | 1.01 | .90 | .92 | .87 | 1.02 | 1.15 |
| A | 1.38 | 1.50 | 1.47 | 1.44 | 1.38 | 1.22 | 1.14 | .97 | 1.04 | 1.16 |
| B | .... | .... | .... | .... | .... | .... | 1.31 | 1.18 | 1.16 | 1.26 |
| C | .... | 1.62 | 1.63 | 1.59 | 1.56 | 1.38 | 1.26 | 1.13 | 1.14 | 1.24 |
| D | .... | .... | .... | .... | .... | .... | 1.43 | 1.28 | 1.25 | 1.33 |
| S.D. | .055 | .033 | .017 | .022 | .02 | .03 | .03 | .04 | .06 | .06 |
| C.V. | 4.0 | 2.1 | 1.1 | 1.5 | 1.4 | 2.3 | 2.3 | 3.5 | 5.2 | 4.8 |
| M.d.r. | .... | .03 | .01 | .02 | .01 | .02 | .03 | .04 | .06 | .06 |

## TABLE 13

## PER CENT NITROGEN IN CRUSHER JUICES

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | .012 | .009 | .008 | .008 | .009 | .009 | .006 | .005 | .007 | .009 |
| A | .014 | .019 | .016 | .021 | .018 | .020 | .016 | .009 | .009 | .011 |
| B | .... | .... | .... | .... | .... | .... | .018 | .014 | .014 | .015 |
| C | .... | .028 | .031 | .037 | .033 | .033 | .027 | .013 | .013 | .015 |
| D | .... | .... | .... | .... | .... | .... | .029 | .017 | .020 | .020 |
| S.D. | .003 | .007 | .005 | .006 | .008 | .009 | .005 | .003 | .003 | .003 |
| C.V. | 21.4 | 29.2 | 20.8 | 20.7 | 32.0 | 34.6 | 21.7 | 23.1 | 21.4 | 20.0 |
| M.d.r. | .... | .005 | .004 | .005 | .006 | .006 | .006 | .003 | .003 | .004 |

## TABLE 14

## REDUCING SUGARS—TONS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | .13 | .10 | .13 | .09 | .08 | .17 | .16 | .36 | .34 | .23 |
| A | .42 | .86 | .79 | .68 | .40 | .39 | .43 | .83 | .87 | .49 |
| B | .... | .... | .... | .... | .... | .... | .57 | 1.71 | 1.92 | .90 |
| C | .... | .82 | .95 | .76 | .48 | .49 | .74 | 1.37 | 1.36 | .86 |
| D | .... | .... | .... | .... | .... | .... | .78 | 1.99 | 2.20 | 1.65 |
| S.D. | .19 | .23 | .18 | .16 | .13 | .15 | .33 | .42 | .68 | .46 |
| C.V. | 45.2 | 27.4 | 20.7 | 21.9 | 29.5 | 34.1 | 52.4 | 28.4 | 42.8 | 47.4 |
| M.d.r. | .... | ns | .13 | ns | ns | ns | ns | .44 | .71 | .48 |

## TABLE 15

## SUCROSE—TONS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | .42 | .81 | 2.16 | 2.34 | 3.82 | 5.07 | 5.14 | 4.27 | 6.74 | 10.47 |
| A | .64 | 2.17 | 4.14 | 5.21 | 6.83 | 8.21 | 10.35 | 11.37 | 15.33 | 17.38 |
| B | .... | .... | .... | .... | .... | .... | 10.60 | 13.30 | 20.26 | 21.31 |
| C | .... | 1.88 | 4.26 | 5.26 | 7.14 | 8.31 | 10.02 | 11.44 | 14.98 | 22.03 |
| D | .... | .... | .... | .... | .... | .... | 8.75 | 11.75 | 14.96 | 22.25 |
| S.D. | .28 | .62 | .92 | 1.49 | 1.74 | 1.61 | 3.91 | 2.71 | 5.45 | 6.64 |
| C.V. | 43.8 | 30.7 | 21.9 | 28.4 | 24.9 | 19.5 | 39.4 | 22.6 | 33.3 | 32.0 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

## TABLE 16

## TOTAL SUGARS—TONS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | .58 | .92 | 2.40 | 3.55 | 4.10 | 5.50 | 5.58 | 4.86 | 7.44 | 11.24 |
| A | 1.10 | 3.13 | 5.15 | 6.22 | 7.59 | 9.04 | 11.32 | 12.80 | 17.01 | 18.79 |
| B | .... | .... | .... | .... | .... | .... | 11.73 | 15.71 | 22.77 | 23.33 |
| C | .... | 2.80 | 5.44 | 6.31 | 7.99 | 9.26 | 11.29 | 13.40 | 16.90 | 24.04 |
| D | .... | .... | .... | .... | .... | .... | 9.99 | 14.36 | 17.63 | 25.07 |
| S.D. | .49 | .85 | 1.06 | 1.71 | 1.91 | 1.79 | 4.38 | 3.12 | 6.03 | 7.23 |
| C.V. | 44.5 | 28.6 | 20.0 | 27.3 | 24.5 | 19.6 | 39.5 | 22.2 | 32.5 | 31.7 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

## TABLE 17

## MILLABLE CANE—TONS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 7.30 | 9.59 | 19.71 | 21.36 | 30.83 | 36.88 | 37.04 | 42.29 | 58.78 | 73.23 |
| A | 14.65 | 40.03 | 51.99 | 57.42 | 59.03 | 64.33 | 77.64 | 95.88 | 125.32 | 117.59 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 83.48 | 129.08 | 177.26 | 151.50 |
| C | ..... | 38.90 | 55.93 | 58.61 | 62.42 | 66.47 | 80.85 | 107.55 | 132.96 | 157.13 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 75.65 | 123.49 | 146.99 | 176.56 |
| S.D. | 6.51 | 10.64 | 9.30 | 13.84 | 13.51 | 12.43 | 31.21 | 25.90 | 49.47 | 49.28 |
| C.V. | 44.6 | 26.9 | 17.2 | 23.9 | 22.3 | 19.0 | 39.3 | 22.7 | 34.0 | 32.7 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

## TABLE 18

## COMMERCIAL SUGARS—TONS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | .02 | .51 | 1.59 | 2.09 | 3.47 | 4.40 | 4.33 | 3.67 | 5.33 | 7.70 |
| A | .02 | .66 | 2.28 | 4.15 | 5.40 | 6.51 | 7.98 | 8.66 | 12.31 | 13.54 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 8.25 | 9.71 | 14.54 | 16.14 |
| C | ..... | .58 | 2.15 | 3.79 | 5.42 | 6.49 | 7.60 | 7.70 | 11.09 | 16.49 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 7.04 | 7.60 | 10.14 | 17.05 |
| S.D. | .05 | .37 | .65 | 1.45 | 1.42 | 1.50 | 3.00 | 1.94 | 4.09 | 5.43 |
| C.V. | 250.0 | 59.7 | 29.5 | 36.3 | 26.3 | 23.1 | 39.0 | 23.1 | 34.1 | 34.4 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

## TABLE 19

## YIELD PER CENT CANE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | .21 | 5.2 | 8.1 | 9.9 | 11.2 | 12.1 | 11.6 | 8.8 | 9.2 | 10.7 |
| A | .20 | 1.5 | 4.3 | 7.1 | 9.1 | 10.2 | 10.4 | 9.1 | 9.8 | 11.5 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 9.9 | 7.5 | 8.3 | 10.7 |
| C | ..... | 1.3 | 3.8 | 6.4 | 8.6 | 9.6 | 9.4 | 7.1 | 8.3 | 10.4 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 9.4 | 6.2 | 7.1 | 9.7 |
| S.D. | .40 | .66 | .78 | 1.14 | .76 | 1.30 | .85 | 1.07 | 1.05 | 1.08 |
| C.V. | 20.0 | 47.1 | 19.5 | 17.0 | 8.5 | 13.1 | 8.7 | 14.3 | 12.5 | 10.2 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | 1.1 | 1.1 | 1.1 |

## TABLE 20

## NITROGEN IN TOTAL DRY WEIGHT—POUNDS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 29.2 | 21.9 | 40.2 | 39.0 | 48.5 | 56.9 | 50.0 | 55.6 | 74.4 | 85.8 |
| A | 57.8 | 132.0 | 126.2 | 131.8 | 119.8 | 125.6 | 122.8 | 122.8 | 140.1 | 141.0 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 165.8 | 195.7 | 248.5 | 193.9 |
| C | ..... | 152.5 | 166.2 | 175.8 | 174.6 | 166.7 | 168.1 | 160.4 | 172.6 | 194.5 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 183.0 | 211.5 | 214.0 | 271.6 |
| S.D. | 16.88 | 37.59 | 31.54 | 34.67 | 38.18 | 32.51 | 59.55 | 39.01 | 64.45 | 75.95 |
| C.V. | 29.2 | 26.4 | 21.6 | 22.5 | 25.9 | 22.2 | 37.2 | 22.6 | 33.3 | 37.9 |
| M.d.r. | ..... | ns | 23.1 | 25.4 | 27.9 | 23.8 | ns | 40.6 | 67.0 | 79.0 |

## TABLE 21

## $P_2O_5$ IN TOTAL DRY WEIGHT—POUNDS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 28.1 | 25.5 | 46.0 | 48.5 | 71.5 | 88.9 | 87.5 | 96.7 | 128.4 | 168.4 |
| A | 35.1 | 65.9 | 78.1 | 86.2 | 92.1 | 97.4 | 110.4 | 125.7 | 174.0 | 173.9 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 121.0 | 158.5 | 219.5 | 171.4 |
| C | ..... | 62.2 | 65.7 | 67.4 | 77.6 | 79.4 | 97.0 | 129.7 | 152.6 | 204.5 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 90.7 | 132.0 | 145.3 | 182.0 |
| S.D. | 9.20 | 15.13 | 15.54 | 22.44 | 22.73 | 20.91 | 42.36 | 32.62 | 61.36 | 63.36 |
| C.V. | 26.2 | 23.6 | 21.6 | 29.2 | 26.8 | 23.7 | 40.5 | 23.9 | 35.5 | 34.6 |
| M.d.r. | ..... | ns | 11.4 | 16.4 | ns | 15.3 | ns | ns | ns | ns |

## TABLE 22

## $K_2O$ IN TOTAL DRY WEIGHT—POUNDS PER ACRE

| Plots | 3½ mos. Sept. | 5½ mos. Nov. | 7½ mos. Jan. | 8½ mos. Feb. | 9½ mos. Mar. | 10½ mos. Apr. | 11½ mos. May | 14½ mos. Aug. | 17½ mos. Nov. | 20½ mos. Feb. |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 143.1 | 139.6 | 234.0 | 224.4 | 311.7 | 333.4 | 331.2 | 274.1 | 444.6 | 680.9 |
| A | 216.8 | 425.8 | 457.6 | 427.4 | 463.1 | 479.3 | 575.8 | 467.0 | 600.4 | 782.6 |
| B | ..... | ..... | ..... | ..... | ..... | ..... | 616.3 | 582.6 | 779.6 | 856.2 |
| C | ..... | 448.6 | 438.0 | 369.2 | 437.4 | 455.8 | 560.1 | 485.9 | 597.3 | 951.3 |
| D | ..... | ..... | ..... | ..... | ..... | ..... | 503.8 | 448.7 | 513.4 | 895.4 |
| S.D. | 80.8 | 101.78 | 113.51 | 105.90 | 100.40 | 126.12 | 229.93 | 98.26 | 191.85 | 288.26 |
| C.V. | 37.3 | 23.3 | 25.3 | 26.6 | 22.3 | 27.0 | 40.8 | 19.8 | 30.8 | 33.1 |
| M.d.r. | ..... | ns | ns | ns | ns | ns | ns | ns | ns | ns |

# Sugar Prices

## 96° CENTRIFUGALS FOR THE PERIOD JUNE 16, 1944, TO SEPTEMBER 15, 1944

| Date | Per pound | Per ton |
|---|---|---|
| June 16, 1944, to September 15, 1944 | 3.75¢ | $75.00 |

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